SOCIAL AND EMOTIONAL PROCESSING IN THE BROADER AUTISM PHENOTYPE

Doctor of Philosophy

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Abstract

The major aim of this thesis was to examine social-emotional processing in the broad autism phenotype (BAP), through looking at typically developing individuals with high and low autistic traits as measured by the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001). In addition, as autism is strongly genetic developmental disorder, a subsidiary aim was to gain information about the relation between genetics and social-emotional processing within autism through examination of first-degree relatives of people with clinically defined autism.

Autism spectrum disorders (ASD) are characterized by social-emotional difficulties, particularly in face processing difficulties and difficulties in understanding intentions and emotion. There are several explanations for those difficulties. One of explanations, based on a social-orienting model of autism, posits that social-emotional difficulties in people with autism are results of their pervasive problems in social motivation. This explanation considers that social-emotional difficulties are results of abnormalities in the brain structures responsible for orienting to socially salient stimuli, such as the amygdala. Another, contrasting, explanation of social-emotional difficulties and particularly face processing difficulties in autism is based on visual-perceptual characteristics of the disorder, focusing on the local perceptual style in autism, with close attention to detailed features. Three experiments are reported in this thesis, chosen to inform on and contrast these explanations of autism. Electroencephalographic (EEG) and Magnetoencephalographic (MEG) studies examined face and emotion processing in individuals with higher and lower autistic tendencies. These experiments examined sensitivity to facial orientation (upright *cf* inverted faces), and also the processing of emotion in faces when presented under masking conditions that impacted on conscious awareness. The third study examined biological motion processing in the BAP.

Main results showed that: 1) Reduced face inversion effect in individuals with high autistic traits was accompanied a reduction in EEG amplitudes for the N170 negativity recorded over the left hemisphere. 2) Only individuals with high autistic traits showed enhanced P2 (positive ERP peak with latency around 200ms) and LPP (Late Positive Potential, an ERP component that peaks around 300 ms) amplitudes for inverted emotional faces (sad and happy). 3) Only individuals with low autistic traits showed enhanced N200 amplitude for subliminally presented happy faces. 4) Alpha and beta spectral band decreases

over regions containing the Mirror Neuron System (MNS) indicated that activity in each group depends on the region.

Results of research in this thesis indicate that there are socio-emotional differences between individuals with higher and lower autistic traits, and also differences between first-degree relatives of individuals with autism compared to participants without first-degree relatives with autism. However, it is also shows that both perceptual and more socio-emotional explanations have roles in those differences.

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma, except where due reference is made in the text of the thesis. To the best of my knowledge, this thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

Signed ………………………………….

Dated………………………………….

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ABBREVIATIONS

ACC	Anterior Cingulate Cortex
ADHD	Attention Deficit Hyperactivity Disorder
ADOS-G	Autism Diagnostic Observation Schedule – Generic
AFHI	Autism Family History Interview
AMG	Amygdala
ANOVA	Analysis of Variance
AQ	Autism Spectrum Quotient
ASD	Autism Spectrum Disorder
BA	Brodmann Area
BAP	Broad Autism Phenotype
BAPSS	Broad Autism Phenotype Symptom Scale
BAPQ	Broad Autism Phenotype Questionnaire
BOLD	Blood Oxygen Level Dependant
BM	Biological Motion
BMT	Broken Mirror Theory
CFMT	Cambridge Face Memory Test
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders 4th ed.
DSM-5	Diagnostic and Statistical Manual of Mental Disorders 5th ed.
DTI	Diffusion Tensor Imaging
DZ	Dizygotic
EEG	Electroencephalogram
EF	Executive Function
EFT	Embedded Figures Test
EMG	Electromyography
EOG	Electrooculography

EPF	Enhanced Perceptual Functioning
EQ	Empathy Quotient
ERD	Event-related Desynchronisation
ERP	Event-Related Potential
ERS	Event-Related Synchronization
E-S	Empathising-Systematising
FFA	Fusiform Face Area
FG	Fusiform Gyrus
fcMRI	Functional Connectivity Magnetic Resonance Imaging
fMRI	functional Magnetic Resonance Imaging
HFA	High Functioning Autism
HFPDD	High Functioning Pervasive Developmental Disorders
HSFs	Higher Spatial Frequencies
IFG	Inferior Frontal Gyrus
IOG	Inferior Occipital Gyrus
IPL	Inferior Parietal Lobule
IPS	Intraparietal Sulcus
IQ	Intelligence Quotient
LFA	Low Functioning Autism
LGN	Lateral Geniculate Nucleus
LH	Left Hemisphere
LPP	Late Positive Potential
LSFs	Lower Spatial Frequencies
M	Mean
MEG	Magnetoencephalogram
MEP	Motor Evoked Potential
MNS	Mirror Neuron System

MNI	Montreal Neurological Institute
MPFC	Medial Prefrontal Cortex
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
ms	Millisecond
MT	Middle Temporal
MTG	Middle Temporal Gyrus
MZ	Monozygotic
M1	Primary Motor Cortex
NAcc	Nucleus Accumbens
NIRS	Near-Infrared Spectroscopy
OFA	Occipital Face Area
OFC	Orbitofrontal Cortex
PET	Positron Emission Tomography
PDD	Pervasive Developmental Disorders
PDD-NOS	Pervasive Developmental Disorder Not Otherwise Specified
PLDs	Point-Light Displays
pSTS	Posterior Superior Temporal Sulcus
Pulv	Pulvinar
RH	Right Hemisphere
ROI	Region of Interest
SC	Superior Colliculus
SCDC	Social and Communication Disorders Ch
SD	Standard Deviation
SE	Standard Error
SRS	Social Responsiveness Scale
SQ	Systemizing Quotient

SSVEP	Steady state visual evoked potential
STG	Superior Temporal Gyrus
STS	Superior Temporal Sulcus
S1	Primary Somatosensory Cortex
TBV	Total Brain Volume
TD	Typically Developing
TFR	Time Frequency
Th	Thalamus
TMS	Transcranial Magnetic Stimulation
ToM	Theory of mind
TPJ	Temporoparietal Junction
V1	Primary Visual Cortex
V4	Visual Area 4
V5	Visual Area 5
VEP	Visual Evoked Potential
Vol	Volume
vMMN	Visual Mismatch Negativity
vMPFC	Ventromedial Prefrontal Cortex
VPP	Vertex positive potential
WASI	Wechsler Abbreviated Scale of Intelligence
WCC	Weak Central Coherence
WCST	Wisconsin Card Sort Task

CHAPTER 1 –

EXPLAINING AUTISM - COGNITIVE THEORIES

3. Autism Spectrum Disorders - Introduction

Autism spectrum disorder (ASD) or autism has been described as a neurodevelopmental disorder, but is mostly diagnosed by behaviour. In the previous version of the Diagnostic and Statistical Manual of Mental Disorders IV (APA, 2000) it was situated within the Pervasive Developmental Disorders (PDD) category that included Asperger's syndrome, Autism, Pervasive Developmental Disorder not otherwise specified (PDD-NOS), Childhood Disintegrative Disorder and Rett's syndrome. However, changes recently introduced (in May, 2013) by DSM-5 situated autism on a "spectrum", which recognises dimensions of severity of ASD symptoms and replaces the PDD subgroups into an umbrella term "Autism Spectrum Disorder" (ASD) with no subtypes (APA, 2013; Lai, Lombardo, & Baron-Cohen, 2013a; Lai, Lombardo, Chakrabarti, & Baron-Cohen, 2013b; Lenroot, & Yeung, 2013). In this way, the new definition is more precise in delineating significant individual variability in the spectrum.

New DSM-5 also introduces changes into the characterisation of autism that was previously characterised by impairments in the triad of behavioural domains: social impairments, communication disturbances and deficits in the development of language, and the presence of repetitive or restrictive behaviour and interests (DSM-IV, APA, 2000). Impairment in imagination was also often mentioned as a part of the diagnosis, related to a lack of spontaneous pretend play in autistic individuals (Frith, Morton, & Leslie, 1991). However, the new DSM-5 (APA, 2013) changed a number of symptom domains through characterizing ASD by two behavioural domains: social communication domain and restricted repetitive behaviours and interests. Disorders in language development are now excluded from the diagnostic criteria, but are classified as co-occurring conditions, implying that a language disorder can be present or absent in a person with ASD (Lai et al., 2013 a, b).

One of aims of the new conceptualisation of ASD was to emphasise the heterogeneity within ASD. Before the recent revision of DSM, the ASDs included autism and Asperger's syndrome, with an unresolved question about whether they represent different disorders. Asperger's syndrome was considered to lie at the higher end of the autistic spectrum (Macintosh, & Dissanayake, 2004), but still shared some impairments with autism. For example, individuals with Asperger's syndrome also have social impairments and deficits in communication and behaviour, as they have difficulties in understanding and relating to other people. Their biggest problems are within non-verbal communication and sensory processing. Additional similarities that they share with autism are restricted interests and repetitive

behaviours. However, they have a normal intelligence quotient (IQ) and do not have speech and language impairment (Baron-Cohen & Belmonte, 2005; O'Connor, Hamm & Kirk, 2005; Sanders et al., 2008). Some studies have found more severe brain abnormalities in individuals with Autism, whereas intermediate abnormalities were found in individuals with Asperger's syndrome, suggesting that the Asperger disorder lies on the mild end of the autism spectrum (Jou, Minshew, Keshavan, & Hardan, 2010; Lotspeich et al., 2004). Ellis and Gunter (1999) proposed that Asperger's syndrome primarily involves right-hemisphere performance deficits affected by "dysfunctional white matter" (p. 192). This suggestion is based on "The White Matter Hypothesis" of Rourke and his colleagues (1989, 1995), which was primarily related to Nonverbal learning disabilities (NLD). Rourke and colleagues considered NLD to be caused by some neurodevelopmental disorder that primarily affects white matter. Atypical white matter, in its turn, affects various tasks dependent on the right hemisphere, particularly non-verbal tasks, but also tasks requiring inter-hemispheric cooperation. It is still speculative to consider that the White Matter hypothesis may explain all or some of features of Asperger's syndrome. A recent study (McAlonan et al., 2009) showed that children with Asperger disorder had greater right-sided white-matter deficits compared with the control group, whereas children with high functioning autism had greater white-matter deficits in the left hemisphere. Lotspeich et al., (2004) found enlarged cerebral grey matter volume in high and low functioning autism and that in Asperger disorder it is intermediate between that of high functioning autism and healthy controls, suggesting that cerebral grey matter volume increases with the severity of autism. A detailed meta-analysis of MRI studies of autism and Asperger syndrome (Yu, Cheung, Chua, & McAlonan, 2010) showed that autism and Asperger syndrome differ in the distribution of grey matter. Thus, Asperger syndrome has lower grey matter volume in the right hemisphere and greater grey matter volume in the left hemisphere. Autism has greater volume of grey matter bilaterally. Overall, findings of brain abnormalities that compared Asperger disorder and autism suggest that the autism spectrum can be explained as a spectrum of brain abnormalities (McAlonan et al., 2009). Additionally, it is also suggested that the genetics of individuals with autism and Asperger disorder may be dissimilar, with genetic factors having a more important role in Asperger syndrome than in autistic disorder (Volkmar, Klin, & Pauls, 1998). Furthermore, it was found that individuals with Asperger syndrome are more likely than those with autism to have a family history of depression, schizophrenia and the broader autistic phenotype (Ghaziuddin, 2005). Some genetic susceptibility loci in individuals with Asperger disorder overlap not only with loci

associated with autism, but also with schizophrenia (Ylisaukko-oja et al., 2004), leading Yu et al., (2010) to suggest that Asperger syndrome is closer to schizophrenia-like conditions.

Although autism is usually associated with intellectual disability, with approximately 60-80% of the total ASD population with mild to severe intellectual disability (Fombonne, 2003), there is no strong evidence for a distinctive IQ profile among individuals with autism (Baron-Cohen & Belmonte, 2005). Their IQ scores can be quite diverse (Baron-Cohen & Belmonte, 2005; Charman et. al., 2011). However, it was suggested that IQ (Baron-Cohen, & Belmonte, 2005; Rutter, 1978) and the level of language function by age six (Baron-Cohen & Belmonte, 2005; Szatmari, Bryson, Boyle, Streiner, & Duku, 2003) can be strong predictors of clinical diagnoses of ASD. Based on the presence or absence of an intellectual disability, individuals with autism can be divided into "low-functioning autism" (LFA) and "high-functioning autism" (HFA). Individuals in the HFA group, although having normal intelligence, often have speech and language difficulties (Sanders, Johnson, Garavan, Gill, & Gallagher, 2008), and restricted and repetitive behaviours and interests were found to be equally present in both groups (Happé & Ronald, 2008).

Autism was first identified as a coherent disorder in 1943 by Leo Kanner, a child psychiatrist at Johns Hopkins University (Kanner, 1943). In his seminal work, Kanner described 11 boys with "inborn autistic disturbances of affective contact" (1943, p. 250; in Geschwind, 2009), and although the cases included in this report suffered multiple problems, social and emotional characteristics of the disorder were emphasised in Kanner's description. Kanner suggested that individuals with autism ". . . have come into the world with an innate inability to form the usual, biologically provided affective contact with people" (p. 250). This emphasis is consistent with the present day focus on social dysfunction when searching for root causes of autism, because social deficits are viewed as specific to autism in comparison to other neuropsychiatric disorders (APA, 1994; Schultz, 2005). Contrary to this, the other two domains of the diagnostic triad are frequently shared with some other disorders. For example, communication problems and deficits in the development of language are a dominant characteristic of specific language impairment. Repetitive behaviours and restricted interests are not specific to autism, but shared by many mental retardation syndromes (Bodfish, Symons, Parker, & Lewis, 2000; Schultz, 2005). The population prevalence of autism was previously estimated to be about 4 in 10,000 children (Wing & Gould, 1976), but the current estimate is 22 in 10,000, equivalent to 1 in 455 children (Fombonne, Quirke, & Hagen, 2011). The increased prevalence is probably due to changes in diagnostic criteria for the disorder.

Although the cause of autism is unknown, its early onset and familial pattern suggest a strong genetic and biological basis (Bailey et al., 1995; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). There is no core neurological mechanism that could explain symptoms found in autism, but the triad of deficits as defined in DSM-IV on which the majority of neuroimaging research is based suggests specific sets of neuropsychological deficits. However, the pattern of brain abnormality in autism is complex, with many perceptual and cognitive systems spared. For example, individuals can have severe autism together with normal or even superior intelligence (Schultz, 2005). It is expected that a better understanding of cognitive deficits in autism will lead to improved descriptions and definitions of specific cognitive phenotypes (Schultz, 2005).

Throughout this dissertation, "autism" delineates ASD, and specific ASD categories will be mentioned when needed.

1.2. Psychological/cognitive theories of autism

Over the past few decades, researchers have tried to explain the nature of the cognitive deficit in autism with a goal of finding a primary cognitive marker for autism (Pellicano, 2011). Several theories have gained particular importance: executive functions, weak central coherence and theory of mind. These theories are known as "single-deficit theories", as they try to explain autism in terms of single cause underlying cognitive atypicalities (Pellicano, 2011). However, recent empirical investigations have challenged the notion of a single cause for the cognitive abnormalities found in autism, and recently there has been a shift to multiple cognitive explanations.

1.2.1. Executive dysfunction

The executive dysfunction theory of autism suggests that autistic symptomatology has a cause in broader, executive control processes that are not specific to social cognition (Joseph & Tager-Flusberg, 2004). Executive functions are higher order functions responsible for guiding flexible, goal-oriented behaviour, and has been proposed to be a cause not only of strong repetitive and stereotyped patterns of behaviour characteristic of autism, but also of impairments in communication and social interaction (Ozonoff, Pennington, & Rogers, 1991). Social and communicative competence requires on-line evaluation and selection of appropriate responses to diverse and multifaceted information (Bennetto, Pennington, &

Rogers, 1996; Joseph & Tager-Flusberg, 2004). However, the set of skills covered by the term "executive functions" vary considerably. Happé et al., (2006) suggested three main domains of functions: (1) planning and working memory, (2) flexibility in thinking and behaviour, and (3) response selection/inhibition. Deficits in executive function have an impact on the functioning of lower-order cognitive processing such as language, perception and action, and intact executive functions are required for complex tasks that require flexibility and the thinking and creation of novel strategies (Sanders et al., 2008). Individuals with autism have shown impairments in all three domains, although the degree of impairment varies for each of them, and those that mostly explain autism are problems with an ability to plan actions and attention shifting (Baron-Cohen, 2008). Frith (1972) was the first to suggest possible executive function impairment in autism, after observing more "rule-bound, repetitive and less unique patterns in a task of spontaneous colour and tone sequence production" in individuals with autism in comparison to healthy controls (cited in Pellicano, 2011, p. 229).

There is a whole range of tests for measuring some aspects of executive function (Hill & Bird, 2006). Traditional tests of executive function include tower tasks (e.g. Tower of Hanoi), the Wisconsin Card Sort Task (WCST), the Stroop test and tests of verbal fluency. Some new tests of executive function have been devised for measuring planning and problem solving abilities (for example, the Action Program, the Hayling Test, etc.; Hill & Bird, 2006). In one of the rare studies that examined the performance of adults with Asperger syndrome across various executive processes, Hill and Bird (2006) found that adults with Asperger syndrome in comparison to a healthy control group showed impaired ability in the newer tests of executive function, but not in the classical tests.

Concerning the primacy and universality of executive function impairments, Ozonoff, Pennington and Rogers (1991) considered executive function to represent a core deficit of autism, based on their finding that 96% of autistic subjects performed more poorly than the healthy control group on executive function tasks. Although they found that 87% of autistic subjects performed poorly on the second-order theory of mind task, they showed that executive functions tasks were better able to distinguish individuals with autism from the control group. However, a study by Pellicano et al., (2006) found a much smaller percentage of autistic children performing lower on executive function tasks than a typically developing control group, with 55% poorer on the Set-Shifting task, and 68% poorer on the ToM task. Furthermore, executive function problems are not only found in individuals with autism, but also in some other disorders, such as Attention Deficit Hyperactivity Disorder (ADHD),

Schizophrenia, Obsessive Compulsive Disorder and Tourette syndrome, (e.g., Nyden, Gillberg, Hjelmquist, & Heiman, 1999; Ozonoff & Jensen, 1999; reviewed in Rajendran & Mitchell, 2007), which suggests that executive function difficulties are not specific to autism. Difficulties in differentiating executive functions between disorders may be the result of the nature of executive function tests, which usually measure multiple executive abilities, and therefore it is necessary to find distinct executive function impairment in individuals with autism that would distinguish them from other disorders (Rajendran & Mitchell, 2007). Several studies that measured planning ability have indicated difficulties in executive function in children with lower IQ (Hughes, Russell, & Robbins, 1994; Mari, Castiello, Marks, Marraffa, & Prior, 2003), implying that planning ability may be related more closely to IQ rather than autistic symptoms.

There are many methodological concerns that prevent final conclusions being drawn from the performance of individuals with autism on executive function tests. For example, methodological differences among studies, such as the choice of tasks and specificity of matching measures between autistic groups and comparison groups can influence results (Russo et al., 2007). Russo et al. (2007) reviewed in detail the performance of individuals with autism on the Wisconsin Card Sorting Test (WCST), which was used by Rumsey (1985) in the initial examination of executive function deficits in autism. Rumsey (1985) found impaired performance on the WCST in individuals with autism compared to the control group, primarily in higher preservative responses, indicating impairment in cognitive flexibility. However, although it is considered that the WCST can highlight difficulties in cognitive flexibilities, it can also rely on other components, such as inhibition, working memory and set shifting. Russo et al. (2007) reviewed the research on this test and showed intact inhibition abilities and working memory among individuals with autism but impairments in set shifting. As executive function is not universally impaired in autistic people, it is necessary to look at the specific components of executive function that are impaired across various tasks when taking into consideration the development of executive function in individuals with autism (O'Hearn, Asato, Ordaz, & Luna, 2008).

Executive function disorders are related to the frontal lobe, specifically to the fronto–striatal and fronto–parietal circuits/pathways (Pennington & Ozonoff, 1996; Baron-Cohen, 2008), and executive dysfunction is found in patients with frontal lobe damage. Individuals with autism have been found to possess frontal cortex abnormalities (Just, Cherkassky, Keller, T.A., & Minshew, 2004) and to have larger activation in premotor areas in inhibition and working memory tasks (Kana, Keller, Minshew, & Just, 2007). Despite strong

resemblance between patients with frontal lobe damage and individuals with autism, particularly in rigid behaviours and concreteness of thoughts and language (Damasio & Maurer, 1978; Pellicano, 2011), individuals with autism do not have any obvious damage to the frontal lobe, but may have experienced disrupted maturation in the prefrontal cortex during developmental stages (Baron-Cohen, 2008). Abnormally large frontal lobes were found in children with autism (Carper & Courchesne, 2000, 2005). Ozonoff et al., (1991) suggested that damage to the prefrontal cortex could explain both executive dysfunction and theory of mind problems in individuals with autism. This suggestion is based on Goldman-Rakic's (1987) hypothesis of the activation of the prefrontal cortex whenever stored information is used for guiding behaviour. However, although widespread prefrontal impairment can be a potential influence in a wide variety of neuropsychological domains, it cannot explain all impairments in autism. An example for it is children with early frontal lesions who do not become autistics.

However, as not all disorders of executive functions show frontal lobe impairment, it is suggested that executive functions in autism may depend on integrated brain function and connectivity (O'Hearn et al., 2008). Thus, it is proposed that impairments found in autism may be caused by additional subcortical deficits, including deficits of connectivity between subcortical and cerebellar areas. Abnormal functional connectivity in autism may have a cause in grey and white matter irregularities (O'Hearn et al., 2008). Further brain abnormalities were observed in the form of reduced brain activity in the anterior cingulate cortex of individuals with autism during inhibition tasks (Kana et al., 2007). The corpus callosum was found to be smaller in individuals with autism than those in the control group, which suggests it might play an important role in carrying information related to impaired planning and working memory in autism (Keary et al., 2009).

1.2.2. Weak central coherence

The Central Coherence Theory was formulated by Frith (1989), based on earlier observations of unusually good performances in some tasks by children with autism. Frith (1989) suggested that healthy individuals display "central coherence", which is a natural propensity to integrate diverse information to construct a whole or Gestalt, whereas individuals with autism show an imbalance in integrating information as Gestalt, and instead process information in piecemeal or detailed-focused style. In other words, individuals with autism show "weak" central coherence or an absent drive for central coherence.

The first evidence for the weak central coherence hypothesis in autism came from studies that showed the superior performance of autistic people on visuospatial tasks, such as the Embedded Figures Test (EFT) (Shah & Frith 1983) and the Wechsler Block Design subtest (Shah & Frith, 1993). The main requirement for successfully passing these tests is recognition of segmented figure of smaller constituent components of a figure segmentation of a figure or including smaller constituent components (Rajendran & Mitchell, 2007). As subjects with autism lack a cognitive drive to look at the global form, they perform better on these tasks compared to neurotypical subjects, who show greater salience for the global figure rather than for smaller components (Frith, 1989, 2003; Rajendran & Mitchell, 2007). Further support for the weak central coherence hypothesis comes from research on visual illusion, which showed that individuals with autism succumbed to visual illusion in smaller measures than other groups (Happé, 1996). However, not all studies on visual illusion have found that individuals with autism differ from the control group, which indicates that they may be equally susceptible to it (Ropar & Mitchell, 1999, 2001). Individuals with autism were also found to differ from neurotypical individuals on tasks related to visual discrimination (Plaisted, O'Riordan & Baron-Cohen, 1998a) and visual search (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998b).

Initially, weak central coherence was considered a specific cognitive style, present not only in the visuospatial domain but also in all areas of functioning in autistic individuals. However, the primacy of the weak central coherence theory was later abandoned by Frith and Happé (1994), and was reconsidered to be only one of the primary cognitive atypicalities in autism, along with difficulties in theory of mind and executive control (Happé & Firth, 2006). One important reason for this change was that studies had showed intact global processing in individuals with autism (e.g. Mottron, Belleville, & Ménard, 1999; Ozonoff, Pennington, & Rogers, 1991). Mottron et al., (1999) found a normal global advantage in individuals with autism by using the Navon test (Navon, 1977). The traditional Navon test uses larger letters constructed from smaller letters, which are either the same or different from the large letter (e.g., a H composed of small Ss). Participants are required to report the identity of the large or small letter. New findings suggest that weak central coherence represents superiority in local or detailed-focused processing, rather than being a primary problem in autism (Happé & Frith, 2006). Furthermore, Happé and Frith's (2006) review of previous research found that weak central coherence is only evident in a subset of the autistic population and is also found in other clinical groups such as Williams Syndrome, schizophrenia, depression, and right

hemisphere damage, which suggests that the weak central coherence hypothesis lacks universality and specificity in autism.

Research findings about local and global processing in autism suggest that although a local processing style as observed in individuals with autism may represent a disorder, it can also represent superior processing that is conductive to the development of certain skills (Happé & Frith, 2006; van Lang, Bouma, Sytema, Kraijer, & Minderaa, 2006). This can lead to special talents or "islets of abilities", and also incidences of savant skills, which are exceptionally developed skills/abilities in some very specific areas such as music or mathematics (Baron-Cohen, 2008; Pellicano, 2011).

It is not clear what neural mechanisms underlie weak central coherence in individuals with autism. It is suggested that problems may lie in diffuse changes in neural connectivity (Happé & Frith, 2006), and that poor global processing is related to reduced structural or functional connectivity between different cortical regions (White, O'Reilly, & Frith, 2009). It was also suggested that individuals with autism have reduced integration of specialised local networks in the brain caused by a deficit in temporal binding (Brock, Brown, Boucher, & Rippon, 2002). In addition, deficits in global integration of stimuli and in motion processing may be explained by magnocellular visual pathway deficits in autism spectrum disorders (Milne et al., 2002; Plaisted et al., 1999; Spencer et al., 2000).

1.2.3. Theory of mind

Theory of mind (ToM) is the ability to attribute mental states to oneself and others, which allows for the prediction and interpretation of the behaviour of both oneself and others (Joseph & Tager-Flusberg, 2004; Pellicano, 2011; Premack & Woodruff, 1978). According to the ToM hypothesis in autism, individuals with autism have impairment in this important ability. The majority of research has focused on tests that examine a person's understanding of false beliefs, in which it has been found that individuals with autism show significant impairment (Baron-Cohen, Leslie, & Frith, 1985; Joseph & Tager-Flusberg, 2004). A false belief task requires a person to make a distinction between the world as it really is and the way it might be represented (usually incorrectly) in the mind of another person (Tager-Flusberg, 2007). A classic example of a false belief task is the Sally-Anne Test (Wimmer & Perner, 1983), which consists of the following story being presented to participants: Sally puts a ball in a basket and goes away. Anne takes the ball from the basket and hides it in a box. Participants are asked to predict where Sally will look for the ball when she returns.

False belief tasks often involve mistaken representations of reality, and are therefore considered to mark the emergence of a representational understanding of the mind (Joseph & Tager-Flusberg, 2004; Wimmer & Perner, 1983). Impairment in the representation of mental states is a suggested explanation for the communication and reciprocal social interaction difficulties that individuals with autism experience, as this ability is considered a prerequisite for normal social interaction and communication (Frith & Happé, 1999). It is suggested that the realisation of having a mind involves the development of a special type of cognition called meta-representation that enables humans to understand that they possess thoughts and feelings and that their own thoughts and feelings can differ from those of other people (Mundy, 2003). This leads people to try to understand the thoughts and feelings of others, which makes possible to predict the behaviour of others. Impaired meta-representation, as observed in individuals with autism, may impair their capacity in social interaction with others and significantly impair their communication abilities (Baron-Cohen, 1995; Happé, 1993; Leslie, 1987). Previous studies found relationships between the performance on theory of mind tasks and various social difficulties (e.g. Frith, Happé, & Siddons, 1994; Hughes, Soares-Boucaud, Hochmann, & Frith, 1997b, 2000; Pellicano, 2011). Leslie (1987) also suggested that a "metarepresentational" impairment in autism could be a cause of the lack of imaginative or pretend play in autistic children.

The lack of ToM in children with autism was first observed in a seminal study by Baron-Cohen et al., (1985). ToM in this study was assessed by using the classic Sally-Ann test. The study showed that a majority of lower-functioning children with ASD failed a first order false-belief task that typically developing children pass at around age four, although children with autism had mental and verbal abilities above the 4-year level (Boucher, 2012; Tager-Flusberg, 2007). These findings led to the description of autism as a primary cognitive deficit in the ToM (Baron-Cohen, 1995; Baron-Cohen et al., 1985; Frith et al., 1991; Leslie, 1987), with the argument being that various social and communication impairments in individuals with autism have a psychological cause in the form of ToM impairments (Baron-Cohen, 1995; Mundy, 2003; Boucher, 2012). Baron-Cohen (1989b) even proposed that ToM impairment can explain all the behavioural difficulties found in autism, including repetitive behaviours and narrow interests. However, critics responded that ToM could not have a causal role in the development of autism because in most studies on ToM some children with autism were able to pass false belief tasks (Pellicano, 2011). A response to this criticism was that although some children with could pass first-order false belief tasks, they failed more difficult second-order false belief tasks (i.e. in the form of "Mary thinks that John thinks the

ice cream van is in the park"; Perner & Wimmer, 1985) despite being significantly older than the age at which typically developing children pass that task (6-7 years) (Baron-Cohen, 1989a). Based on these findings, Baron-Cohen (1989a) suggested that the development of ToM in autism is not completely absent but is rather developmentally delayed. However, some later studies found that adults with Asperger syndrome can pass both 1st and 2nd order false belief tasks (Bowler, 1992), suggesting that there is a group of individuals within the autistic spectrum who have a better social understanding than those without ToM ability (Frith & Happé, 1999). Some authors suggested that although able individuals with autism may succeed in false belief tasks, it does not mean they developed a ToM, but that they could be using compensatory reasoning to successfully complete ToM tests (e.g. Happé, 1995; Ozonoff et al., 1991). It is suggested that autistic individual's understanding of mental states is different from the automatic or intuitive understanding of mental states that neurotypical individuals have. Neurotypical individuals are not formally taught how to read other people's minds, but learn this through interactions in their social environment. One of explanation for this is that the typical brain is programmed to pick up and develop such understanding rapidly (Baron-Cohen, 2008). It was found that individuals with autism develop this ability at a later age, and also require higher verbal ability than normal children in order to accomplish this (Happé, 1994, 1995), but understanding of false beliefs and other cognitive states still remains a challenge for them (Tager-Flusberg, 2007). Compared to typically developing children who approach ToM tasks intuitively and inherently possess the general cognitive skills necessary for verbal processing, memory and inhibition of spontaneous responses, children with autism approach ToM tasks as logical-reasoning problems, relying strongly on language and other non-social cognitive processes rather than on intuitive social insight into other people's mental states (Tager-Flusberg, 2007). They also need to be explicitly taught a principle of how other people's minds work in order to grasp it (Baron-Cohen, 2008). In other words, although some highly-functioning children can pass false belief tasks, this understanding is not based on social "intuition" like in typically developing children. They continue to have problems with "fluid mentalizing in everyday situation" (Frith et al., 1991, p. 436). Frith et al., (1991) cite the example of a high functioning person with autism who complained that "other people seem to have a special sense by which they can read other people's thoughts" (p. 436).

The suggestion that individuals with autism employ compensatory reasoning for solving ToM tasks has indirect support in some behavioural and neuroimaging studies. For example, some behavioural studies have indicated that although certain individuals with

autism pass standard false belief tasks, they underperform on more naturalistic and complex tests of ToM that assess what other people are thinking or feeling, including an understanding of irony (Happé, 1994) and the attribution of mental states of moving geometric figures (Castelli, Frith, Happé, & Frith, 2002; Klin, 2000). They also perform relatively poorly on the "Eye test", in which participants are required to read a person's state of mind from isolated pictures of eyes that show various emotional states (Baron-Cohen et al., 2001a; Baron-Cohen, Wheelwright, & Jolliffe, 1997). Neuroimaging studies have found that during the processing of ToM tasks individuals without autism activate their social brain network (e.g. medial pre-frontal cortex and temporo-parietal junction), as well as areas involved in executive control (Frith & Frith, 2003; Saxe, Carey, & Kanwisher, 2004a). Contrary to this, individuals with autism activate brain areas associated with general problem-solving skills (e.g. Happé et al., 1996). Furthermore, different patterns of eye movements were found in individuals with autism compared with healthy individuals during false belief tasks (Senju, Southgate, White, & Frith, 2009), although they were able to pass them. Senju et al., (2009) suggested that individuals with autism might be spontaneously mentalising less, which is usually used automatically by neurotypical individuals of all ages, including infants. Thus, the use of compensatory reasoning in false belief tasks by individuals with autism, as mentioned above (Happé, 1995), implies that they lack some intuitive abilities that neurotypical individuals use to pass these tasks (Boucher, 2012). Boucher (2012) suggested that this intuitive ability to understand thinking or feelings in other people may be universally impaired in individuals with autism.

Presently, considering impaired ToM as a "single cause" explanation of all the behavioural diagnostic characteristics of ASD has generally been abandoned (Boucher, 2011; Boucher, 2012; Happé, Ronald, & Plomin, 2006). It is generally accepted that the ToM impairment in ASD can account for their social and communication impairments, but not for other diagnostic characteristics of autism (Baron-Cohen, 2008; Boucher, 2012), such as restricted and repetitive behaviour patterns, nor some of the strengths that are observed in autism, such as superior visual-attention skills (Tager-Flusberg, 2007). However, ToM is still an important topic in ASD literature, but it is now used in a much broader sense, and not only for the ability to pass false belief tests (Boucher, 2012). Presently, some new terms were introduced, such as "mentalising" and "mindreading", which includes not only classical false belief tests, but also the ability to understand others people's intentions and beliefs, and also joint attention and empathy, including reading other minds through social cues such as facial expressions and biological motion (Boucher, 2012). It is suggested that whereas the ToM

hypothesis is based on deficits in the understanding of mental states, social and communication developments begin well before the emergence of ToM skills in typically developing children (Tager-Flusberg, 2007). Hobson (1993) suggested that ToM deficits were based on early emotional impairments. Social and communication skills include emotional and perceptual processes that are the foundation for the development of social cognition. It is suggested that even when individuals with autism pass ToM tests, they show poor performance in tests that require processing social and affective information from different social stimuli. Tager-Flusberg (2001) suggested a broader ToM framework that encompasses traditional social-cognitive components of mental-state understanding, and also social-perceptual components that include understanding of mental states from various social stimuli, such as eye-gaze perception, face and facial emotion recognition. In this framework, mind reading is considered as one component of empathy, and it is suggested that empathy is not possible without an emotional response to another person's state of mind (Baron-Cohen, 2008). Baron-Cohen's (1994, 1995) more extensive "mindreading" system includes not only understanding mental states, but also innate mechanisms for eye-gaze detection and shared attention. According to this explanation, the shared attention mechanism is specifically damaged in autism, which in turn impairs the development of ToM. However, the mindreading system was revised in 2005 to include the ability to recognize emotions and to show empathic reactions towards others' (Chakrabarti & Baron-Cohen, 2006). This revised system did not reject the importance of knowledge of mental states of others, suggesting that this knowledge could influence processing and experience of emotions.

Functional imaging studies that attempted to locate brain systems underlying the ToM functioning in typically developing subjects (e.g., Baron-Cohen et al., 1999; Brunet, Sarfati, Hardy-Bayle, & Decety, 2000; Castelli et al., 2000; Fletcher et al., 1995; Gallagher et al., 2000; Gallagher, Jack, Roepstorff, & Frith, 2002; Goel, Grafman, Sadato, & Hallett, 1995; McCabe, Houser, Ryan, Smith, & Trouard, 2001; Russell et al., 2000; Vogeley et al., 2001; Völlm et al, 2006; with reviews in Amodio & Frith, 2006; Frith & Frith, 2003) suggest that a neural network associated with ToM involves several regions (the anterior paracingulate, the STS and the temporal poles), and that frontal brain regions are found to be more active during ToM tasks than control tasks. However, some studies also showed functional underconnectivity between the frontal lobe and other regions in autistic subjects relative to control subjects during ToM task (e.g., Castelli et al., 2002; Kana et al., 2009).

1.2.4. Empathising-systemising

The empathising-systemising theory of autism (Baron-Cohen, 2002) argues that social and communication difficulties in autism can be explained by deficits in empathy processes, and these deficits can vary in degree. In this way, the term empathising encompasses a range of other terms related to the understanding of another person's mind, most importantly, the theory of mind and empathy. These two components of empathy are named cognitive and affective empathy (Baron-Cohen, 2008). This understanding of empathy includes both attribution of mental states to oneself and others or mindreading (Baron-Cohen, 1994; Leslie, 1995) and an appropriate emotional response to others' mental states (Baron-Cohen & Belmonte, 2005).

The empathising-systemising theory considers individuals with autism to be deficient in empathy, whilst in the same time emphasises the cognitive strengths found in autism (Baron-Cohen, 2002, 2008). These strengths are explained by the concept of systemising – the drive to analyse, explore or create various systems. There are many kinds of systems, from ordinary objects like stones or cars, to more abstract systems such as musical notation (Baron-Cohen, 2008). People make sense of various systems by noting regularities and inferring the rules found in those regularities (Baron-Cohen, 2002, 2008). Systemising was found either intact or superior in individuals with autism (Baron-Cohen, Richler, Bisarya, Gurunuthan, & Wheelwright, 2003; Lawson, Baron-Cohen, & Wheelwright, 2004), and some of the evidence for this comes from the Systemizing Quotient (SQ), although this test was mostly designed for children and adults with Asperger syndrome, rather than those with classic autism (Baron-Cohen, 2008).

Referring to two important factors, empathising and systemising, the strength of this theory may lie in its ability to explain both the social and non-social features in autism, something that was not possible to find in other theories. Social and communication impairments are explained by an underdeveloped ability to empathise, whilst narrow interests, repetitive behaviours and even savant abilities can be explained by strong interests with mechanical or other systems that lead to an exceptional depth of processing, rather than considering them to represent executive dysfunction (Baron-Cohen, 2002, 2004, 2005, 2008; Baron-Cohen & Belmonte, 2005; Baron-Cohen & Wheelwright, 2002). Baron-Cohen (2008) suggests that high-functioning individuals with autism or Asperger syndrome might express their systemising in different way than individuals with classic autism. For example, whereas

individuals with high-functioning autism may be practising frisbee moves intensively, individuals with classic autism may be spinning round and round (Baron-Cohen, 2008).

At present, the evidence for superior systemising in individuals with autism is mostly based on self-rating of preference and abilities (Baron-Cohen et al., 2002), though there are some studies that tried to link behavioural tasks performance and scores on questionnaires, thus tapping systemising and empathising (SQ and EQ) (e.g. Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti, 2009; Brosnan, Daggar, & Collomosse, 2010; Lawson et al., 2004).

Because of the clear differences that have been found between males and females in empathising and systemising, with females performing better on tasks or situations that require empathising and males on tasks that require systemising, a new theory was suggested called the "extreme male brain" theory of autism (Baron-Cohen, 2008). This theory is an extension of the systemising account of autism and found support because of a strong drive to analyse and control non-social systems that are found predominantly in males rather than females. Based on this, autism is explained as "an extreme of the typical male profile" (Baron-Cohen, 2008, p. 71). This view is not completely original as it was suggested by Hans Asperger in 1944, but it has potential to increase our understanding as to why autism is more prevalent in males than females. This theory is similar to the empathising and systemising theory in that it posits two independent dimensions, but suggests that individual differences in the population in regard to these dimensions produces five "brain types" (Baron-Cohen, 2008, p. 71):

1)   Type E - individuals with stronger empathy compared to systemising (E > S)

2)   Type S – individuals with stronger systemising compared to empathy (S > E)

3)   Type B – individuals with a balanced (hence B) type, with comparable empathy and systemising (S = E)

4)   Extreme Type E – individuals with above average empathy, but very low systemising (E >> S)

5)   Extreme Type S – individuals with above average systemising, but very low empathy (S >> E).

This is an idealised model, according to which more females have a Type E brain and more males have a Type S brain, whereas autistic individuals predominantly have an Extreme Type S brain or an extreme male brain. In reality, as Baron-Cohen explains, empathising and systemising are two processing styles that can co-exist in the same person. Although a person may inherently adopt the empathising or systemising style, they will be capable of using the

other style to some extent. However, the two processing styles are independent, and reflect specific brain types (Baron-Cohen, 2002; Bowler, 2007). Evidence for the extreme male brain theory mainly comes from the SQ and EQ, however other tests also support it. For example, women were found to score higher than men on the Reading the Mind in the Eyes Test, and men were found to score higher than women on the Embedded Figures Test, which is a test of attention to detail (reviewed in Baron-Cohen, 2008).

More support for the extreme male brain theory was also found in neurological findings. Simon Baron-Cohen (2008) summarised existing findings that support the notion that there are some brain regions that are smaller in males than females on average, and smaller still in individuals with autism (suggested regions are: anterior cingulate, superior temporal gyrus, inferior frontal gyrus), and that some brain regions are bigger in males than females on average, and even bigger in individuals with autism (suggested regions are: amygdala in early life, overall brain size/weight, head circumference). However, these theses are still waiting for a full support from more empirical research. Support for the extreme male theory is also coming from measuring the ratio between the length of the second and the fourth finger, or the 2D:4D ratio (Manning, Baron-Cohen, Wheelwright, & Sanders, 2001; Manning, Scutt, Wilson, & Lewis-Jones, 1998). Results indicated that this ratio is lower in typical males than typical females, and in autism is found to be lower compared to typical controls (Manning et al., 1998, 2001). These findings are explained by the level of prenatal testosterone levels. However, the extreme male brain theory still needs more research support.

Baron-Cohen's empathising-systemising theory has many similarities with the central coherence theory (Frith & Happé, 1994) in showing a strong attention to detail in persons with autism, but differs from the central coherence theory by suggesting that superior local processing does not presuppose impairment of integration of global information (Baron-Cohen & Belmonte, 2005). For example, according to empathising-systemising theory, a person with autism will show a strong drive to learn a new system if there are underlying rules in this system. Contrary to this, the weak central coherence hypothesis predicts that they will fail to learn a whole system or the relation between its parts (Baron-Cohen, 2004), and that systemising may be a consequence of strong attention to detail (Baron-Cohen & Belmonte, 2005).

1.2.5. Social motivation theory of autism

The social motivation theory of autism does not have an official place among the various theories that have been proposed to explain the main impairments found in autism, but the ideas in this theory complement other ones. Whereas social cognition in autism is explained by the ToM and is extended into the empathising and systemising account, they cannot explain motivational factors behind the development of social skills and social cognition. Recently a group of researchers tried to determine whether decreased social motivation and attention is a primary deficit in autism, suggesting that they have a negative downstream effect on social cognition skills by depriving individuals with autism of crucial social learning opportunities (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Dawson, Meltzoff, Osterling, & Rinaldi, 1998; Kohls, Chevallier, Troiani, & Schultz, 2012; Schultz, 2005). Social motivation is described as "a set of psychological dispositions and biological mechanisms biasing the individual to preferentially orient to the social world (social orienting), to seek and take pleasure in social interactions (social reward), and to work to foster and maintain social bonds (social maintaining)" (Chevallier et al., 2012, p. 231) (**Figure 1-1**). In evolutionary terms, an important role of social motivation is to prepare individuals to adjust and collaborate with others.

Figure 1-1. Biological mechanisms of social motivation (from Chevallier et al., 2012, p. 232).: Social motivation is subserved by a network of brain regions that interact with each other and each is more important in specific aspects of motivation. Those regions include the

amygdala, the ventral striatum, and the orbital and ventromedial regions of the prefrontal
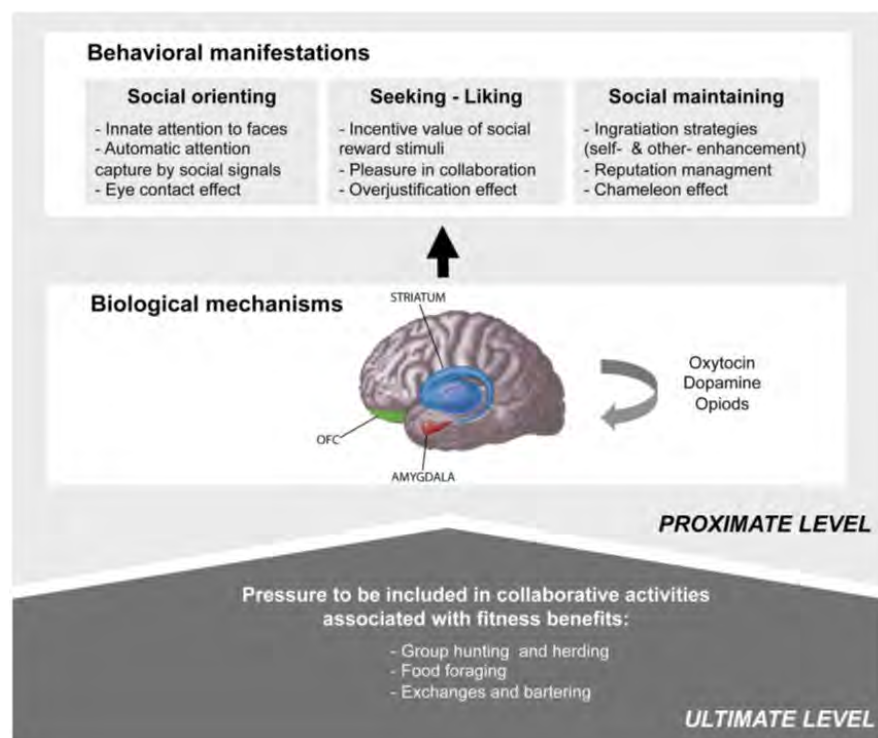
cortex. The amygdala plays an important role in social orienting by directing attention towards salient stimuli, such as human faces and bodies, eyes and biological motion. Amygdala's strong interaction with the central striatum and orbitofrontal cortex (OFC) gives support to this recognition of salience in stimuli. The ventral striatum has an important role in recognising the value of both social and non-social reward stimuli. Finally, the OFC transforms reward information into strategies for behaviour and actions.

Subsequently, the social motivation deficit hypothesis in autism suggests a diminished or absent interest in attending to socially relevant stimuli or engaging in social activities, including reciprocal social interaction. These characteristics may be present in individuals with autism from an early age, disrupting social learning experiences, and as a consequence the development of normal social skills (Chevallier et al., 2012). With reference to the previously mentioned description of social motivation theory, all behavioural manifestations of social learning – social orienting, social seeking and liking, and social maintaining – are considered to be impaired in autism (Chevallier et al., 2012). Social orienting impairment and the inability to share attention with others, noticed already in early research on autism, has been included into the diagnosis of autism (APA, 1994). Among the most commonly observed difficulties experienced by children with autism is impairment in joint attention. Joint attention involves sharing information with another person and is considered to be crucial for development of language and social competence (Bachevalier & Loveland, 2006; Courchesne, Chisum, & Townsend, 1994; Mundy, 1995). It emerges between 9 and 18 months of age in typically developing children (Bakeman & Adamson, 1984; Taylor & Hoch, 2008) but is profoundly impaired in individuals with autism (Lekam & Ramsden, 2006; Mundy, Sullivan, & Mastergeorge, 2009). Moreover, the absence of joint attention prior to age one is considered to be one of the earliest indicators of autism (Baron-Cohen, Allen, & Gillberg, 1992). Children with ASD show reduced eye contact and orienting to social stimuli. The absence of spontaneous orienting to social stimuli in children with autism was referred as social orienting impairment by Dawson et al., (1998). Early social orienting impairment deprives children with autism of essential social information that is imputed during crucial developmental stages, altering normal brain and behavioural development (Dawson et al., 2004a). Examples of the early disruption of orienting to social stimuli are found in retrospective studies of home videos showing that 1-year old infants, later diagnosed with autism, pay less attention to people, show impaired joint attention and lack orienting to their names when compared to both typically developing and mentally impaired children of the

same age (Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002). Other home videos have showed decreased orienting to their names in 8- to 10-month old infants, later diagnosed with autism, compared to typically developing infants of the same age (Werner, Dawson, Osterling, & Dinno, 2000). Dawson et al., (1998) showed that children with autism, when compared to children with Down's syndrome and typically developing children, showed an absence of orienting to both social and non-social stimuli, although this lack of orienting was more frequent for social stimuli. Children with autism also showed greater impairment in joint attention ability, with a strong correlation between the severity of joint attention ability and social orienting ability. Dysfunctional social attention in autism was also observed with auditory stimuli, showing absent preferential attention towards socially salient sounds such as human voices, over non-social noise (Klin, 1991; Kuhl, Coffey-Corina, Padden, & Dawson, 2005).

The seeking and liking aspect of social motivation was also found to be impaired in autism. For example, a great proportion of adults with ASD have fewer friends than average, achieve low scores on friendship questionnaires (Baron-Cohen & Wheelwright, 2003), and lack a preference for collaboration with others (Liebal, Colombi, Rogers, Warneken, & Tomasello, 2008). However, probably the most important development impairment is the absence of declarative pointing (Swinkels et al., 2006) and joint attention (Mundy et al., 2009).

Social maintaining is another aspect of behaviour that is found to be less pronounced in autism. For example, compared to neurotypical individuals, autistic people put less effort into strategically presenting their self-image through using laughter for negotiating social interactions (Hudenko, Stone, & Bachorowski, 2009). They also show impairment in social reputation processing, as observed in a task that required charitable donations under conditions with an observer and without an observer (Izuma, Matsumoto, Camerer, & Adolphs, 2011). Whereas neurotypical individuals donated more in the presence of an observer, the high-functioning autistic group was not influenced by the presence of an observer. Another study showed that individuals with autism also differ in comparison to typically developing individuals in displaying social (self-conscious) emotions such as guilt and embarrassment/coyness (Hobson, Chidambi, Lee, & Meyer, 2006).

The lack of social motivation in autism has been related to the impaired reward value of social stimuli and, at the biological level, the reward circuitry dysfunction (Kohls et al., 2013). For individuals with autism social activities are less rewarding than for neurotypical individuals, leading to diminished social motivation to engage in these activities. For

example, impaired face processing in autism is argued to be a consequence of the absent interest in social stimuli early in development (Dawson, Webb, & McPartland, 2005). Brain abnormalities related to rewards were found in the orbitofrontal-striatum-amygdala circuit (Bahevalier & Loveland, 2006; Chevallier et al., 2012), particularly in response to socially salient stimuli such as faces (Schultz et al., 2000). Several functional magnetic resonance (fMRI) studies examined brain activation in response to monetary rewards in adults with autism and found aberrant brain activation in the brain reward circuitry, particularly in the anterior cingulate cortex (ACC) (Schmitz et al., 2008) and nucleus accumbens (NAcc) (Dichter et al., 2012). A diminished neural response to both social and monetary rewards was also found in autistic children (Scott-Van Zeeland et al., 2010; Kohls et al., 2013). However, whereas Scott-Van Zeeland, Dapretto, Ghahremani, Poldrack and Bookheimer (2010) found significant differences between the autistic and control groups only in response to social reward, with significant impairment in the processing of social rewards in autistic children, Kohls et al., (2013) found hypoactivation within the amygdala/prefrontal/NAcc circuitry in response to both social and monetary reward, suggesting a general reward dysfunction in autism. A general reward dysfunction in autism would be contrary to the social motivation deficit theories of autism (Chevallier et al., 2012; Dawson et al., 2005; Schultz, 2005), as it is based on greater neural malfunctions in response to social rewards in autism. However, neither monetary reward dysfunction in autism is supported universally. For example, no group differences between individuals with autism and healthy control were found in reward circuitry in response to monetary rewards in children with autism by using fMRI (Schmitz et al., 2008) or EEG (McPartland, Crowley, Perszyk, Mukerji, & Naples, 2012). Thus, it is not yet clear whether the impaired reward circuitry in autism represents a general dysfunction of reward circuitry or a greater malfunction of reward circuitry in response to social rewards. It is also suggested that low social motivation in autism may additionally be affected by their increased attention to some groups of non-social stimuli that absorb attentional resources that are typically needed for social attention (Kohls et al., 2012; Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008). However, another explanation for social impairments in individuals with autism that confronts the social motivational hypothesis states that the unpredictability of social situations leads to increased social anxiety in individuals with autism, causing social avoidant behaviour (Kohls et al., 2012; Wood & Gadow, 2010).

1.3. Are cognitive functions fractionated in autism?

An unresolved question in the multiple deficit view of autism is whether the triad of impairments in this disorder are independent of each other. Cognitive theories of autism are not sufficient to explain the full range of autistic symptoms, leading to a proposal that core characteristics of the behavioural phenotype of autism are explained by coexisting multiple atypicalities in three core domains – theory of mind, executive function and central coherence (Happé, Ronald, & Plomin, 2006). Together with the relative independence of these three cognitive functions, they are also considered to underlie different impairments in autism (Happé et al., 2006; Happe & Ronald, 2008). Early epidemiological data established the long accepted assumption that behavioural symptoms of autism have common genetic, cognitive and neural causes (Wing & Gould, 1979). However, the authors noticed that in some children only certain aspects of the triad were present. A recent study found evidence of modest correlations between the core domains of autism (social impairments, communication difficulties, and restricted, repetitive behaviours or interests) (Dworzynski, Happé, Bolton, & Ronald, 2009).

The precise relationship between ToM and executive functions is not clear. For example, there is some evidence of correlation between performance on various aspects of EF and measures of social functioning (e.g., Griffith, Pennington, Wehner, & Rogers, 1999; Hill & Bird, 2006; Ozonoff et al., 1991; McEvoy, Rogers, & Pennington, 1993; Russell, Mauthner, Sharpe, & Tidswell, 1991; Zelazo, Jacques, Burack, & Frye, 2002), although there is evidence of no correlation between social functioning and EF measures (Joseph & Tager-Flusberg, 2004). Suggestions of the primacy of EF over ToM in autism is based on findings that indicated better discrimination of autism with EF tasks than with ToM and on findings of a correlation between performance on executive function tasks and false belief understanding in autism (e.g., Ozonoff et al., 1991). Some aspects of executive function, including planning, flexibility and working memory, are found to be impaired in children with autism, and those aspects of executive function are found to be significantly related to performance on false belief tasks by both children with autism and healthy children (Joseph & Tager-Flusberg, 2004; Ozonoff et al., 2004; Tager-Flusberg, 2007). Pellicano (2007) found that ToM and EF are dissociable, with impaired ToM and intact EF. These results suggest that EF can be present with impaired ToM, a finding that was supported by a longitudinal study (Pellicano, 2010b) with young children with autism. This study indicated that EF was predictive of children's ToM scores throughout early childhood, with no relation in the opposite direction.

These findings are explained by the difference in development of EF and ToM in typically developing population, with EF to be later-maturing than ToM abilities (e.g., Diamond, 2002), which suggests that greater differences between autistic and neurotypical groups could be found in greater measure at later stages of development (Pellicano, 2007). However, the relationship between ToM and EF is complex and multifactorial and at present it is mostly accepted that each of them is important in explaining autism. One explanation for the difficulty in finding relationships between various cognitive impairments is that cognitive tests are rarely "process pure" (Brunsdon & Happé, 2013, p. 2). Thus, false beliefs tests usually possess high verbal and executive demands (Frith & Happé, 1999), as they require the inhibition of one's own beliefs (Brundson, & Happé, 2013). Some EF tests may also require social skills (Brundson & Happé, 2013; Ozonoff, 1995; Pellicano, 2007). This explanation of the primacy of EF over ToM was later revised, with the suggestion that difficulty in holding in mind and shifting between cognitive domains can lead to impaired mentalising ability (Russell, 2002).

There is even less understanding about the relationship between ToM and the weak central coherence theory, because they have not been investigated as extensively as the relationship between ToM and EF. Several studies have found no relationship between ToM and central coherence (Happé, 1997; Pellicano et al., 2006). No correlations were observed between weak central coherence and the severity of autism's signs and symptoms, including social competence (Teunisse et al., 2001). Although Burnette et al., (2005) showed that verbal measures of central coherence were related to ToM ability, the relationship was not significant after IQ was taken into account. Similarly, Pellicano et al., (2006) found that correlation between ToM and weak central coherence was not significant after age, verbal ability and non-verbal ability were taken into account. Jarrold, Butler, Cottington, and Jimenz (2000) found that poor ToM was related to weak central coherence in both typically developing children and children with autism, and although the results did not prove a causal relationship, the authors suggested that weak central coherence causes impaired ToM because weak central coherence prevents a person from integrating separate information in order to understand complex social situations. As this relationship was observed only after the differences between the verbal mental ages or both verbal mental age and chronological age were taken into account, they suggested that this finding represents individual rather than developmental differences between ToM and central coherence. However, according to a new explanation of the weak central coherence account as a perceptual bias or cognitive style, it is considered to be one aspect of cognition in autism, alongside difficulties in social cognition

(Frith, 1989, 2003; Happé & Frith, 2006). This is supported by previously mentioned findings of detail-focused processing being present in subjects with autism independent of their level of ToM (e.g., Happé, 1997; Jolliffe & Baron-Cohen, 1997, 1999).

However, there is extensive research on face processing in autistic individuals that shows abnormal face processing. Faces can be processed configurally or featurally, and individuals with autism were found to process faces predominantly in a featural manner (e.g. Deruelle et al., 2004), which can be explained by their bias towards detailed information (Behrmann, Thomas, & Humprheys, 2006).

Although Baron-Cohen's empathising-systemising theory suggests that empathising and systemising stand in contrast to each other, few studies have examined the correlation between them. Partial evidence for their negative correlation is found in Baron-Cohen et al.'s (2001) study of 15 boys with Asperger syndrome.

Studies that examined the relationship between central coherence and EF have found them to be mostly independent of each other (Booth, Charlton, Hughes, & Happé, 2003; Happé, 1997; Pellicano, 2010b; Pellicano et al., 2006). Although Pellicano et al., (2006) showed some association between central coherence and EF in children with autism, this association was not significant after co-varying age and ability was taken into account. Pellicano (2010a, 2010b) investigated the development of cognitive atypicalities in autism over a 3-year period. Importantly, results showed a significant developmental relation between ToM and EF, but EF and central coherence appeared relatively independent. Although there is some evidence for a significant association between central coherence and executive function in children with autism (Pellicano et al., 2006), there is no conclusive evidence for a link between theory of mind and weak central coherence in individuals with autism (e.g. Pellicano et al., 2006; Baron-Cohen, & Hammer, 1997; Jarrold, Butler, Cottington, & Jimenz, 2000).

More research is needed to establish the relationship between various cognitive accounts of autism. Current research suggests that the strongest relationship is between ToM and executive functions, however it is necessary to examine the relationship between executive functions and social difficulties in autism that are not measured solely by ToM tests. However, Happé and Frith (2006) proposed that autism should be considered as a disorder with a number of anomalies, including global-local processing, social cognition and executive functions. They support the view from genetic analysis studies that examined the measure in which social and non-social behaviours typically observed in autism can be found in typically developing twins. Results showed high heritability of both social and non-social

behaviours but also that they are largely genetically independent (Ronald, Happé, & Plomin, 2005). Other studies also found that the triad of impairments found in autism (social impairments, communication impairments, restricted repetitive behaviours and interests) are highly heritable, but also genetically independent of each other (Ronald et al., 2006a; Ronald, Happé, Price, Baron-Cohen, & Plomin, 2006b).

1.4. Summary

Autism is a highly heterogeneous disorder. Recent changes in the definition of Autism Spectrum Disorder (ASD) are a consequence of changes in the understanding of autism, and a major trend in those changes is the recognition of autism more as a condition rather than a disorder, which in its turn influences policies and early support (APA, 2013; Rajendran & Mitchell, 2007). The major cognitive theories of autism - the theory of mind, executive functions and weak central coherence - attempt to provide an explanation of the disorder, each in its own terms. An advancement from earlier stages of research is the recognition that neither one of them can be taken as a single theoretical explanation of autism (lack of uniqueness) nor any of them can explain all sympoms found in autism (lack of universaility), but each of them rather represents a specific aspect of cognition in people with autism (Happé & Frith, 2006). However, empirical investigation of multiple deficits in autism lacks developmental research and only a few studies have showed developmental trends and interactions of multiple deficits through development (Pellicano et al., 2006).

CHAPTER 2 –

SOCIAL-EMOTIONAL FUNCTIONING IN AUTISM

4. Social brain

Understanding how social stimuli are processed in the human brain is fundamental to identifying and making sense of the behaviour of humans (Johnson, 2005). It is also important for recognising abnormalities in social and emotional behaviour. Brothers (1990) suggests that a group of brain areas, termed the "social brain", are specialised for processing social stimuli in higher order primates, and proposed the initial set of structures thought to represent the neural basis of social cognition: the amygdala, the orbitofrontal cortex and the temporal poles. Research on autism has found abnormalities in all of these areas (reviewed in Baron-Cohen & Belmonte, 2005). Recently, additional structures have been added to include the superior temporal sulcus (STS), the fusiform gyrus (FG), amygdala, temporal poles (TPs), medial prefrontal cortex (MPFC), and orbitofrontal cortex (Adolphs, 2003; Johnson, 2005) (**Figure 2-1**). Brain bases of social cognition were also influenced by animal research with the discovery of mirror neurons by Rizzolatti et al. (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Fogassi, & Gallese, 1996). This research has been extended with human subjects (Rizzolatti & Craighero, 2004), giving explanations for physiological bases of imitation and empathy. However, the role of the MNS in empathy is still very controversial, with a recent meta-analysis of brain regions involved in empathy not finding a consistent activation of the MNS regions in empathy (Fan, Duncan, de Greck, & Northoff, 2011). Fan et al., (2011) suggested that although the MNS may not have a central role in empathy per se, but still could have a role in empathy through simulation. Furthermore, Stanley and Adolphs (2013), in their detailed review of social neuroscience and social behaviour, suggest that there is not a single, but rather several systems for processing social information. Withing those systems mirror and empathy are considered to be separate processes (although related), in addition to several other processes, such as social perception and mentalizing.

The present work is primarily concerned with regions involved in visual perception in human.

Figure 2-1: The social brain. A network of brain regions relevant to social processes consists of medial and inferior frontal and superior temporal cortices, and the amygdala. Perceptual inputs for social recognition may be generated in part from regions in the fusiform gyrus and from the adjacent inferior occipital gyrus that is activated in response to faces. Difficulties in this social computational network have been observed in autism. (Adapted from Baron-Cohen & Belmonte, 2005, p. 113).
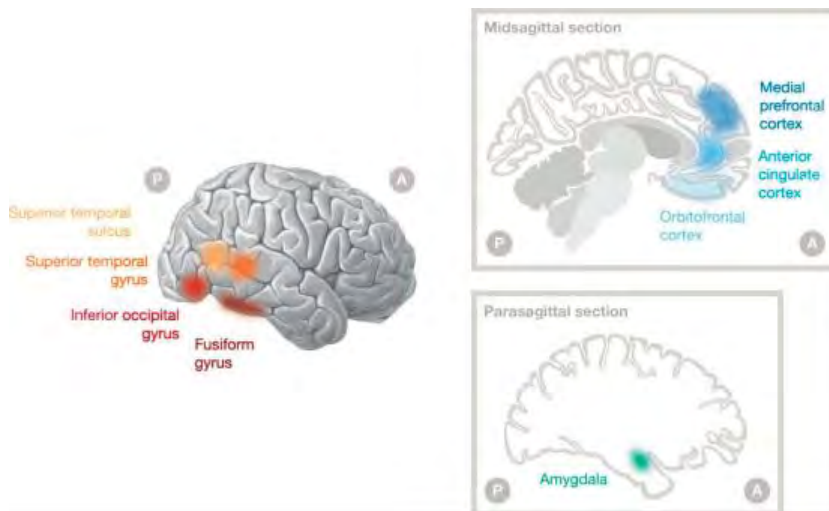
Recent developments in social neuroscience do not accept the idea of strongly modular processing, but instead use a network view of brain functions to explain social cognition and behaviour (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Kennedy & Adolphs, 2012). Moreover, Kennedy and Adolphs (2012) emphasise that one of the salient aspects of social cognition is its dependence on a large number of different areas and their connectivity. This network connection typically depends on rapid and interactive processing and therefore a slightest dysfunction in any of these areas can lead to impairments. Even the important role of the amygdala in emotion processing has been questioned with evidence showing the broad role of the amygdala in social cognition, not only in processing of facial expressions (Herry et al., 2007; Whalen, 2007). However, it is suggested that it is necessary to find out about the networks within which the amygdala participates, rather than the specific functions of amygdala (Kennedy & Adolphs, 2012). In summary, Kennedy and Adolphs (2012) propose that it is obsolete to think about the "social brain" as containing independent structures responsible for specific functions, but rather as a "complex, integrated network – one that can also be dynamically reconfigured and depends on normal social development for its emergence" (p. 565).

Investigation of social cognition in autism has started to take the view of autism as a disorder of brain connectivity (Geschwind & Levitt, 2007), rather than emphasising single structures responsible for social impairments in autism. Recently, Gotts et al. (2012) indicated

that social problems in autism can have a source in decreased connectivity between regions of the social brain and, more selectively, between limbic areas of the brain (e.g. amygdala) important for affective aspects of social processing and other parts of the social brain implicated in language and sensorimotor processes.

Several regions have been particularly implicated in the processing of emotional stimuli, including the prefrontal cortex (PFC), amygdala, hypothalamus and anterior cingulate cortex (ACC) (Dalgleish, 2004). Although in the following chapters special attention will be given to the amygdala, as this region is found to be particularly important for emotion processing and is found to be dysfunctional in autism, the PFC has also been found to have an important role in social cognition, particularly related to reward processing (e.g. Rolls, 2000a).

It has been proposed that social stimuli can be processed by unconscious as well as conscious routes (Adolphs, 2009; Frith & Frith, 2008; Tamietto & de Gelder, 2010). The conscious perception is thought to depend on visual cortices in the temporal lobe, and the unconscious perception on a subcortical route involving the superior colliculus (Adolphs, 2009). An automatic and implicit route at the lower level of social cognition is considered to occur without awareness and is responsible for rapid processing of emotional and social stimuli that typically possess a high ecological importance. On the other hand, the route involving conscious awareness is effortful, occurs at a higher level and is usually slow. Support for unconscious processing of emotions can be found in evolution and neuroscience, where it is suggested that the elaborate human cortex involved in conscious feelings is of a later origin compared to subcortical structures responsible for processing of preconscious information (LeDoux, 1996; Winkielman & Berridge, 2004). The amygdala is considered to be implicated in subcortical processing of faces and the Fusiform Face Area and the Superior temporal gyrus in cortical processing of faces (Adolphs, 2002). Autism research has suggested that people with autism lack implicit mentalising, but have developed explicit metalising through experience and learning (Frith & Frith, 2008), suggesting the importance of examining automatic processing of social information in this disorder.

In following sections, a review of face and facial emotion processing in typical individuals and individuals with autism will be explored, together with regions (the FFA, STS and the amygdala) implicated in face processing and social brain network. Finally, a brief description of the two levels of social cognition, conscious and unconscious, will be shown,

with a suggestion of the importance of the subcortical route for explaining atypical social cognition in autism.

2.1. Face and facial emotion processing

Facial information processing is not only one of the most important functions of the human visual system, but is also one of the most developed perceptual skills in humans (Haxby, Hoffman, & Gobbini, 2000). Faces are important mediums for social communication and essential for normal social functioning and interpersonal interactions (Dawson, Webb, & McPartland, 2005; Duchaine & Yovel, 2008). Equally important for the development of healthy social behaviour is recognition of facial emotional expressions, and it has been suggested that the development of high specialisation for processing facial expressions is a result of the great importance of nonverbal facial information for humans (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Ekman, 2003).

Infants only a few days old prefer faces over other objects, in spite of a still immature cortex and afferent pathway (Johnson, 2005), and from 3 to 6 months old infants develop an expertise for the processing of facial information (e.g., Cassia, Kuefner, Westerlund, & Nelson, 2006; Field, Woodson, Greenberg, & Cohen, 1982; Walker-Andrews, 1997). For example, they can already differentiate familiar from unfamiliar faces (de Haan & Nelson, 1997, 1999), upright from inverted faces (Webb & Nelson, 2001) and can recognise different facial expressions (Nelson & De Haan, 1996). A recent steady-state visual evoked potential (SSVEP) study indicates that 4- to 6-month-old infants are able to process global face structure by integrating local elements (Farzin, Hou, & Norcia, 2012). Research has shown the importance of early experience in the development of face processing, with a sensitive period for the development of face processing proposed to be during the first year of life (Pascalis et al., 2005; Pascalis, de Haan, & Nelson, 2002).

Processing of faces is based on recognition of configural information, and configural processing of faces has been suggested to include three levels of processing (Maurer, Le Grand, & Mondloch, 2002). The first level includes perceiving first-order relations that see an object as a face with the unique arrangement of two eyes above the nose, and the nose above mouth. This is followed by combining facial features into a gestalt, followed by processing second-order relations as spatial distances between features, which represents the basis of

recognition of individual faces. The term "configural processing" was often used for all three types of configural processing, causing inconsistencies in the use of this term.

Expertise in the recognition of faces is also based on sensitivity in recognising the configuration of facial features. Holistic or configural perceptual processing is used by typically developing individuals for face processing, but also for objects of expertise, and feature-based processing for non-face objects (Grelotti, Gauthier, & Schultz, 2002). The face inversion effect represents a classical example of the distortion of the "holistic" face (configuration). It impairs face perception and recognition because humans recognise upright faces more easily and accurately (e.g., Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; Yin, 1969).

2.2. Face inversion

It has been accepted that upright faces are processed qualitatively differently than objects or inverted faces (Duchaine & Yovel, 2008; Haxby et al., 2000). Upright faces are processed holistically whereas non-faces are processed in a more part-based manner, subsequently leading to recognition of the face inversion effect as one of the strongest pieces of evidence for specialised face processing. Although it is not universally accepted what the term "holistic" would mean, it usually implies that faces are viewed as a whole, with face parts processed interactively rather than independently of each other (Maurer et al., 2002; Duchaine & Yovel, 2008).

One of the earliest cognitive studies on the face inversion effect was a simple study that examined the recognition of faces and non-face objects conducted by Yin (1969). The study found that although the recognition of all stimuli was poor when stimuli were inverted, worst recognition was found for inverted faces. In upright orientation, the recognition of facial stimuli was best. This greater distortion in the recognition of inverted faces in comparison to objects is taken as evidence for the specialised system for face processing (Haxby et al., 2000). In other words, the face inversion effect represents an example of perceptual expertise for faces, similar to perceptual expertise for any other object. A person who develops perceptual expertise for an object easily recognises any distortion within that object because of developing a perceptual expertise for it (Gauthier & Tarr, 2002). For example, larger face inversion effects were found for faces of own-ethnicity than other-ethnicity (Rhodes, 1993; Vizioli, Foreman, Rousselet, & Caldara., 2010). The inversion effect

was also found for non-face objects for which a person has an expertise (e.g., dogs, birds, cars and greebles) (e.g., Diamond & Carey, 1986; Gauthier & Tarr, 1997). In brief, perceptual expertise involves shifting from "piecemeal processing to holistic processing" (Schultz, 2005, p. 128).

Bodies are also found to show the same inversion effect like faces, although the same configural mechanisms are not considered to be responsible for the processing of faces and bodies (Minnebusch, Suchan, & Daum, 2009; Reed, Stone, Bozova, & Tanaka, 2003; Yovel, Pelc, & Lubetzky, 2010). Also, developmental studies with infants did not find a strong preference for upright compared with inverted bodies in infants as found in findings of their preference for upright compared with inverted faces, although the ability to discriminate intact and scrambled bodies was found to develop during the second year of life (Slaughter, Heron, & Sim, 2002).

2.3. Face processing in autism

A number of behavioural and neuroimaging studies have indicated that individuals with autism show abnormal face processing from early in life (Behrmann, Thomas, & Humphreys, 2006; Dawson et al., 2002; Dawson et al., 2005). Tasks that examined face processing in this group include visual scanning (e.g., Klin, Jones, Schultz, Volkmar, & Cohen, 2002), memory for faces (e.g., Boucher & Lewis, 1992), facial emotional processing (e.g., Celani, Battachi, & Arcidiacono, 1999; Critchley et al., 2000; Davidson & Dalton, 2003; Hobson, Ouston, & Lee, 1988a; Ozonoff, Pennington, & Rogers, 1990; Teunisse & de Gelder, 2001), incidental face learning (e.g., Boucher & Lewis, 1992), memory for faces (e.g., Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998), recognition of familiar faces (e.g., Blair, Frith, Smith, Abell, & Cipolotti, 2002; Boucher & Lewis, 1992; Boucher, Lewis, & Collis, 1998; Langdell, 1978; Klin et al., 1999; Pierce, Haist, Sedaghat, & Courchesne, 2004), etc.

Face recognition impairments are suggested to be closely related or even at the core of social and communicative impairments found in people with autism (Dawson, Webb, & McPartland, 2005; Hadjikhani et al., 2004; Schultz, 2005). Thus, clarifying the nature of impaired face processing in autism may not only explain the social impairments in autism, but may also help in early diagnosis and treatment of the disorder (Sasson, 2006). The main source of impaired face processing in autism is not yet known, but there are several important suggestions, such as deficit in perceptual processing of faces, memory for faces or disrupted

attention to socially salient stimuli early in life (Dawson, Webb, & McPartland, 2005; Grelotti et al., 2002). For example, the social motivation theory of autism has explained decreased performance on face tasks in autism by reduced social interest in individuals with autism, as for then faces are not socially important (Klin et al., 1999). On the other side, low level visual abnormalities would suggest that face processing difficulties in autism, including identity and emotion processing, are a consequence of perceptual processing, specifically characterised by "locally oriented" perception, regardless of modality or a specific domain such as the processing of faces (Behrmann et al., 2006; Jemel et al., 2006; Mottron et al., 2006; Simmons et al., 2009). These two explanations for face processing in autism serve as bases of this thesis, and they will be mentioned frequently.

However, findings of impaired face processing in individuals with autism are mixed, especially with various face tasks showing different results. People with autism are not, in general, prosopagnosic, and they are considered to have milder face processing impairments than individuals with prosopagnosia (Hadjikhani et al., 2004), as they are found to be able to perform normally on certain tasks of face processing (e.g., Teunisse & de Gelder, 1994). They are suggested to show progressively more impaired performance on face tasks with higher demands on the task or when the task contains elements of emotion recognition (Grelotti et al., 2002; Davies, Bishop, Manstead, & Tantam, 1994).

Weigelt, Koldewyn and Kanwisher (2012) gave a comprehensive review of behavioural studies on face identity processing in autism by distinguishing between qualitative and quantitative differences in face identity recognition (McKone, Crookes, & Kanwisher, 2009) between subjects with autism and subjects with no autism. The qualitative difference refers to how facial identity is discriminated between groups and can give an answer on whether individuals with autism can process faces in the same way as healthy individuals. The quantitative difference refers to how well individuals with autism, when compared to typical control groups, discriminate or remember facial identity. Finding about qualitative differences between groups can show whether individuals with autism are able to show typical "face markers", that is, indicators of typical face recognition, such as the well-known face inversion effect (Yin, 1969). The review of findings related to differences in face identity processing between individuals with autism and the typical control suggested stronger quantitative than qualitative differences (Weiglet et al., 2012). According to this review, no strong evidence for qualitative differences between individuals with autism and healthy controls were found for face identity processing. In contrast, significant quantitative differences were observed between face processing in individuals with autism and typically

developing individuals. Aspects of face identity processing that were observed to be specifically impaired in autism are face memory and discrimination of eyes.

In healthy individuals, recognition of faces is diminished when faces are presented upside-down, whereas non-face objects are not affected in the same measure by inversion (Yin, 1969). Although previous research has revealed an absent or diminished face inversion effect in individuals with autism (e.g., Langdell, 1978; Hobson, Ouston, & Lee, 1988b; Rose et al., 2007; Teunisse & de Gelder, 2003), a detailed review performed by Weigelt et al. (2012) considers the majority of those studies methodologically weak. When compared with typically developing individuals, individuals with autism show normal or sometimes even better performance on the face recognition task for inverted faces (e.g., Hobson et al., 1988b). However, some studies found a decline in performance with face inversion in individuals with autism (e.g., Joseph & Tanaka, 2003; Teunisse & de Gelder, 2003). Joseph and Tanaka (2002) found that in comparison to typically developing (TD) children, children with autism did not use holistic face processing strategies. Some studies have demonstrated that individuals with autism can process faces configurally, similar to typical controls through attention cueing (Behrmann et al., 2006; López, Donnelly, Hadwin, & Leekam, 2004; Nishimura, Rutherford, & Maurer, 2008). This finding indicates that configural processing in autism is not impaired, but it is not their default processing style, relating it to a possible superiority in featural or detail-focused processing rather than a deficit in the weak central processing (Happé & Frith, 2006; Lahaie et al., 2006; Mottron, Dawson, Souliéres, Hubert, & Burack, 2006; Soulières, Zeffiro, Girard, & Mottron, 2011b).

It is suggested that individuals with autism do not develop an expertise for faces because they do not consider faces as special (Sasson, 2006), and therefore they probably do not show developmental improvements in the processing of holistic facial information. This proposal still needs strong experimental evidence. Research on the development of face processing in typical individuals suggests an increase in the capabilities of holistic processing with increasing age, including an increase of the face inversion effect (e.g., Diamond & Carey, 1977; Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Le Grand, & Maurer, 2002; Mondloch, Geldart, Maurer, & Le Grand, 2003; Schwarzer, 2000, 2002). It is thought that a shift from featural to holistic processing can already be present in infancy (e.g., Turati, Sangrigoli, Ruel, & de Schonen, 2004; Schwarzer, Zauner, & Jovanovic, 2007). Strong evidence for adult-like holistic processing in childhood is shown in some studies (e.g., Carey & Diamond, 1994; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007; Pellicano & Rhodes, 2003; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). Discrepancies in

findings about the developmental course in holistic processing of faces are explained by proposing that an early processing of holistic information from faces is present already after birth, but becomes a more predominant mode of face processing later in development due to extended experience with faces (Turati, Macchi Cassia, Simion, & Leo, 2006). Altogether, the current evidence suggests that holistic processing of faces does not show the same development course beyond early childhood in autistic people, although this still requires further and more detailed investigation.

However, it is difficult to say whether the lack of expertise with faces leads to diminished face inversion effect in autism, suggesting perceptual skills difficulties or whether it is more related to social interests, and therefore is more related to the social motivation explanation of social deficits in autism (Grelotti et al., 2002). Early behavioural studies have indicated diminished social interests in children with autism. In a study which used video recordings of first birthday parties it was found that children with autism, in comparison to typically developing children, showed less interest in the faces of other people, were less likely to point to objects or orient to a person calling their name (Osterling & Dawson, 1994). Another study showed that 1 year old children with autism failed to orient to a person calling their name, whereas typically developing 1 year olds showed orienting to a person calling their name (Werner, Dawson, Osterling, & Dinno, 2000). These findings indicate that very young children with autism, compared to a TD control group, already show diminished attention to social stimuli (Dawson et al., 2004a; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998), probably leading to impaired development of face processing in children with autism (Grelotti et al., 2002).

2.3.1. Scanning of faces in autism

The first experimental study of face processing in autism conducted by Langdell (1978) found abnormal patterns of looking at faces in children with autism compared to healthy controls. In this study, although children with autism showed a normal recognition of familiar faces in upright orientation, they had difficulties in identifying faces from eye regions. Instead, they relied more on mouth regions than on eye regions for recognition of both facial identity and emotions. This finding suggests that children with autism do not attend to the same facial features (eyes) like neurotypical children, but show preference for the mouth region. Also, strategies that children with autism used for facial processing indicated a strong reliance on featural processing.

The earliest findings on atypical face processing in autism are supported by several other eye-tracking studies. For example, by using the eye-tracking method and short clips from the Who's Afraid of Virginia Wolf film, Klin, Jones, Schultz, Volkmar, and Cohen (2002) found that adult males with high functioning autism, when compared with healthy participants, focused more on the mouth than on the rest of the face, particularly on the eyes. Although focusing on the mouth during face processing is considered to represent a deficit in the holistic processing of faces, Klin et al. (2002) argued that this finding could be better explained by the inability of individuals with autism to find eyes meaningful or informative. In another eye-tracking study, Pelphrey et al. (2002) found that high-functioning individuals differed from neurotypical individuals in viewing pictures of faces by looking more at external features of the face (e.g., ears, hair lines) and less on the core features of the faces (e.g., eyes, mouth, and nose). However, when scanning the core features, they fixated more on the eyes than the mouth, suggesting that individuals with autism are not strategic in processing faces, and that although they may have a greater preference for fixating on the lower part of the face, this preference is not absolute (Jemel, Mottron, & Dawson, 2006). Dalton et al. (2005) found that during judgment of face expression and familiarity tasks, individuals with autism compared to healthy individuals showed reduced time spent on fixation on the eyes. Groups did not differ on the time spent fixating on the mouth. Spezio, Adolphs, Hurley and Piven (2007) used the "bubbles", a method for visual scanning that shows images with only certain parts of the face visible, and findings indicated that participants with autism were more fixated on the mouth and also showed a greater reliance on the mouth during emotion recognition. By using eye-tracking, Riby and Hancock (2009) showed that subjects with autism exhibited reduced viewing of faces, adding to the evidence that faces do not capture the attention of people with autism.

In summary, previous findings on abnormal scanning of faces in autism provides evidence of abnormal strategies for face processing in the disorder. Findings that people with autism fixate more on the mouth than on the eye region could suggest that individuals with autism do not treat the face as a "special" class of stimulus (Grelotti et al., 2002; Sasson, 2006). The atypical mode of face scanning is also considered to lead to difficulties in face processing. Thus, the lack of spontaneous gaze fixation towards the eye region can lead to difficulties in interpreting information from that region (Riby & Hancock, 2009), such as interpreting mental states from eyes (Baron-Cohen, 1995). However, although it is not easy to explain the predominant reliance on the mouth regions in individuals with autism, recent findings suggest that autistic children do not have a general face scanning abnormality, but

the face scanning abnormality in this population is limited to the eye region, probably because of their tendency to avoid eye contact (Yi et al., 2013).

However, several other studies have not found abnormal viewing of faces in individuals with autism (Rutherford, Clements, & Sekuler, 2007; Rutherford & Towns, 2008; van der Geest, Kemner, Verbaten, & van Engeland, 2002). For example, Rutherford and Towns (2008) found similar scan paths between individuals with autism and the typically developing control group during recognition of simple emotions, but during recognition of complex emotion individuals with autism looked less at the eyes.

Thus, mixed results about face processing in autism suggest the need for more investigation of specific strategies that people with autism apply for face processing. As face perception is a part of general visual information processing, it is difficult to completely separate it from visual processing in general. This is especially true for autism, as abnormal perceptual processing already has an important place in understanding autism within the Weak Central Coherence Hypothesis which suggests that individuals with autism are proficient in processing details of complex visual information, but have difficulties in integrating details to make a coherent whole. This perspective would like to propose that face processing deficits could be explained by more general perceptual deficits. Although there are some studies that found impairments of both facial and non-facial stimuli in children with autism (e.g., Davis, Bishop, Manstead, & Tantam, 1994), indicating a general perceptual impairment that is not specific to faces or emotions in high able autistic and Asperger's syndrome groups, this is not supported in all studies (Boucher, & Lewis, 1992; Hauck et al., 1998).

2.3.2. Facial emotion processing in autism

Children and adults with autism have shown impaired processing of facial emotional expressions compared to typically developing controls (e.g., Ashwin et al., 2006; Celani et al., 1999; Davies et al., 1994; Klin et al., 1999; Rump, Giovannelli, Minshew, & Strauss, 2009; Weeks & Hobson; 1987). However, not all studies have found abnormal emotion processing in autism, particularly the processing of "basic" emotions (e.g., anger, fear, disgust, happiness) (e.g., Adolphs, Sears, & Piven, 2001; Baron-Cohen, Wheelwright, & Jolliffe, 1997; Ogai et al., 2003; Ozonoff, Pennington, & Rogers, 1990; Teunisse & de Gelder, 1994; Piggot et al. 2004; Ponnet, Roeyers, Buysse, De Clercq, & Van der Heyden, 2004). There are different explanations for absent group differences in basic emotion

recognition, with some suggesting that it may be attributable to possible compensatory strategies in some autistic groups, particularly those with higher verbal abilities or older age (Grossman, Klin, Carter, & Volkmar, 2000; Prior, Dahlstrom, & Squires, 1990), but also to heterogeneity of symptom severity in ASD groups. Some methodological differences in studies could also be a contributing factor for conflicting findings, such as the low number of participants (Ashwin et al., 2006). It is also proposed that people with autism may have deficits in processing more complex emotions, rather than basic emotions (Adolphs et al., 2001; Baron Cohen, Spitz, & Cross, 1993; Golan, Baron-Cohen, & Hill, 2006).

It has been proposed that differences in emotion perception between autistic and typically developing groups are less obvious when emotions are presented for a longer time, due to the preferential cognitive style of processing in autism, which includes preferential processing of details instead of a whole, as explained by the "weak central coherence" hypothesis (Frith, 2003). It is thought that although focusing on details in social communication may allow individuals with autism to recognise emotional expression when they have more time, it may be detrimental in more naturalistic contexts, where emotions are presented very briefly (Tracy, Robins, Schriber, & Solomon, 2011). Typically developing individuals show accuracy in recognising even very briefly presented facial expressions, suggesting that for this group emotion perception is an efficient process, and this includes even complex, self-conscious emotions, such as pride and shame (Tracy & Robins, 2008; Tracy et al., 2011). Several studies examined processing of briefly presented facial expressions in autism but with inconsistent results. Some of them indicated difficulties in autistic groups for briefly presented facial expressions (e.g., Clark, Winkielman, & McIntosh, 2008; Rump et al., 2009), whereas others found normal recognition of briefly presented facial expressions in autism (Tracy et al., 2011). For example, Homer and Rutherford (2004) used a relatively short presentation time in their delay matching task with facial expressions and revealed correct perception of facial expressions in individuals with autism. Short presentation time of the face stimuli is considered to encourage holistic processing of faces (Celani et al., 1999; Hole, 1994). Differences in those findings can be explained by differences in methodology, but can also suggest that the influence of the systemising style of thinking in autism on emotion recognition needs further explanation. The answer to this question may be particularly important as it is suggested that abnormalities in rapid emotion processing may contribute to difficulties in empathy and adaptive social development (Clark et al., 2008).

Further evidence for abnormal processing of facial expressions in autism can be found in neuroimaging studies, which have indicated that during emotion recognition participants with autism show greater activation in brain regions (e.g., the precuneus) associated with focusing on irrelevant facial features, whereas participants with no autism show greater activation in regions related to emotion processing (e.g., the amygdala), including those associated with holistic and automatic processing of emotional stimuli (e.g., Critchley et al. 2000; Hall, Szechtman, & Nahmias, 2003; Santos, Rondan, Rosset, Da Fonseca, & Deruelle, 2008; Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004). Individuals with autism are found to show particular difficulties in the recognition of complex social information, such as embarrassment and trustworthiness, from nonverbal expressions (Adolphs et al., 2001; Heerey, Keltner, & Capps, 2003), and this difficulty is explained by their detail-focused style of processing information, as recognition of socially complex information requires more holistic and emotion-focused perception, and for which typically developing groups show amygdala activation (Adolphs et al., 2001; Pinkham, Hopfinger, Pelphrey, Piven, & Penn, 2008).

2.4. Neural bases of social cognition and face processing

Understanding core social impairments in autism, including face perception, have benefited greatly from the development of new neuroimaging techniques, particularly structural and functional magnetic resonance imaging (s/fMRI). MRI shows a high degree of spatial resolution as well as contrast sensitivity leading it to become a widespread method for brain imaging (Stigler, McDonald, Anand, Saykin, & McDougle 2011). Functional MRI (fMRI) measures changes in blood oxygenation and sMRI is able to measure total brain volume (TBV) and can also measure grey and white matter microstructure in the brain. All this enables a better understanding of the brain. Several of the most important brain regions that have been found to be involved in social cognition and face processing in typically developing brains, and are also found to be dysfunctional in autistic brains, are the fusiform gyrus, the amygdala, the superior temporal sulcus (STS). A brief description of those regions and findings related to autism will be described in following text.

2.4.1. Fusiform face area (FFA)

The perception of faces has been associated with activation of the region of the fusiform gyrus that is usually activated bilaterally, but more often is larger over the right than the left hemisphere (Halgren et al., 1999; Kanwisher, 2000; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Puce, Allison, Gore, & McCarthy, 1995; Schultz, 2003).

Kanwisher and et al. (1997) referred to the fusiform gyrus as the fusiform face area (FFA) because it showed much higher fMRI responses to faces than non-face stimuli. It was also found to be activated by any other stimulus containing facial information, such as cartoon faces and Mooney faces (Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000). However, it is less activated by scrambled faces, other body parts or objects (Kanwisher et al., 1997; McCarthy et al., 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996). Inverted faces failed to activate the FFA, but instead activated areas more responsive to non-face objects at the ventral object vision pathway (Haxby et al., 1999; Kanwisher, Tong, & Nakayama, 1998). Several studies found activation of the FFA for bodies (Hadjikhani & de Gelder, 2003; Peelen & Downing, 2005; Schwarzlose, Baker, & Kanwisher, 2005).

Although the FFA is considered to be specialised exclusively for faces, its specificity for face processing is not universally accepted (e.g. Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Gauthier, Skudlarsi, Gore, & Anderson, 2000; Gauthier, Curran, Curby, & Collins, 2003; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999), leading to different interpretations for the functional specification of this brain area. For example, according to the perceptual expertise model (Gauthier et al., 1999, 2000), the FFA is not specialised exclusively for faces, but instead for any individual object for which a person shows perceptual expertise (Gauthier, Williams, Tarr, & Tanaka, 1998; Gauthier et al., 1999), suggesting that it is a product of learning and experience. Supporting this view, an fMRI study found bigger activation in the FFA in bird experts when viewing birds than cars, and in car experts when viewing cars than birds (Gauthier et al., 2000). The FFA was also found to be activated through "extensive" perceptual training with greebles (Gauthier et al., 1999). However, the perceptual expertise model still needs more conclusive evidence. For example, contrary to this model, Rhodes, Byatt, Michie and Puce (2004) examined the FFA in regard to face-specificity, individuation, and expert individuation hypotheses and results strongly supported face-specificity hypothesis.

A different explanation of face perception is proposed by a distributed representation model of face perception (Haxby et al., 2000; Hoffman & Haxby, 2000). According to this

model, different aspects of face perception – unchangeable (e.g., the identity of the face) and changeable (e.g., emotional expressions, eye gaze) - affect different cortical regions. This model indicates the predominant role of the lateral FG and inferior occipital gyrus for processing the unchangeable features of the face, and the superior temporal sulcus (STS) for processing the changeable features of the face (Haxby et al., 2000; Puce, Allison, Bentin, Gore, & McCarthy, 1998). According to this model, although the FFA is not involved in processing of emotional expressions, this idea has been challenged recently by contrary reports that found the FFA to be involved in expression processing (Fox, Moon, Iaria, & Barton, 2009; Ganel, Valyear, Goshen-Gottstein, & Goodale, 2005; Harry, Williams, Davis, & Kim, 2013; Xu & Biederman, 2010). Some studies found stronger FFA modulation by fearful in comparison to neutral faces (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Vuilleumier, Armony, Driver, & Dolan, 2001). An activation of the FFA was also found in a task with attention directed to both emotional expression and to identity, suggesting that identity and expressions are processed by an interactive network and the FFA is a part of that distributed brain network (Ganel et al., 2005).

2.4.1.1. FFA in autism

The hypoactivation of the FFA is considered to be a neurofunctional marker of autism (Schultz et al., 2003), and there have already been numerous fMRI studies that have shown the hypoactivation of the FFA in persons with autism during face perception tasks (e.g., Critchley et al., 2000; Hubl et al., 2003; Pierce, Muller, Ambrose, Allen, & Courchesne, 2001; Piggot et al., 2004; Schultz et al., 2000; Wang et al., 2004). The first fMRI study that found hypoactivation of fusiform gyrus to faces in autistic subjects (Schultz et al., 2000) showed that hypoactivation of the FFA to facial stimuli in autistic subjects, compared to neurotypical controls, is accompanied by increased activity in regions normally implicated in object processing. The FFA in autistic subjects is found to be structurally and functionally altered in comparison to healthy individuals, as observed in increased grey matter volume and reduced grey matter density and the number of neurons in the FFA (Kwon, Ow, Pedatella, Lotspeich, & Reiss, 2004; Rojas et al., 2006; van Kooten et al., 2008).

However, there is not a uniform explanation of the meaning of the hypoactivation in the FFA in autism. One possible explanation is related to the role of experience in formation of the visual cortices (Schultz, 2003; Schultz et al., 2000; Grelotti et al., 2001), which is in accord with the expertise model of face processing. According to this explanation, people

with autism do not develop expertise in face perception because they pay much less attention to the face than typically developing subjects. Thus, as children with autism do not pay attention to faces in one the most important stages of development, there is weaker maturation of the ventral temporal visual areas in this population. The ventral temporal visual areas are found to be quite plastic, particularly during early development (e.g., Gaffan, Gaffan, & Harrison, 1988). However, Schultz et al. (2003) suggested that this interpretation does not fully explain the actual causes of autism, but is merely an outcome of having autism. In other words, it is a result of reduced interest in other people and reduced attention to their faces, which developmentally results in under-responsive FFA. Based on this, the hypoactivation of the FFA can be considered as a biological marker of autism (Schultz et al., 2003).

Another explanation for hypoactivation of the FFA in autism is based on findings from eye tracking studies that found abnormal scan paths of faces in individuals with autism compared to healthy individuals (Klin et al., 2002; Pelphrey et al., 2002), particularly focusing on the reduced time spent on visually scanning of the eyes in subjects with autism. A study that combined fMRI and eye-tracking showed that reduced fixations on the eyes are related to the fusiform hypoactivation to faces in autism (Dalton et al., 2005). Differences in the FFA activation between autistic subjects and typical controls were found to be smaller in studies with tasks that draw attention to the eyes (Hadjikhani et al., 2004; Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2007; Perlman, Hudac, Pegors, Minshew, & Pelphrey, 2011; Pelphrey, Morris, McCarthy, & LaBar, 2007). For example, Hadjikhani et al. (2004) used the fixation point in the centre of the stimuli to ensure that images are attended by participants in the same way, and did not find differences in the fusiform gyrus activation between individuals with autism and typical individuals. The FFA activation in autism has also been found to be influenced by the familiarity of faces, with more typical responses found during processing of familiar than unfamiliar faces in subjects with autism (e.g., Grelotti et al., 2005; Pierce et al., 2004; Pierce & Redcay, 2008), suggesting that people with autism show more interest and subsequently give more attention to familiar faces (Bahrick, Netto, & Hernandez-Reif, 1998).

As the FFA has an important role in the "social brain" network, it has been proposed that individuals with autism do not show impairments only in the FFA, but more broadly in the network of cortical regions underlying social cognition (Kleinhans et al., 2008). This argument is supported by functional connectivity analysis, which showed reduced connectivity between fusiform and other face processing regions (Kleinhans et al., 2008;

Koshino et al., 2008; Thomas et al., 2011). Several studies examined the FFA within the social brain network by using Heider and Simmel's (1944) animations in which geometric shapes require attribution of mental states. Studies indicated that subjects with autism compared to typical subjects had difficulties in extracting social meaning from those animations (e.g., Abell, Happé, & Frith, 2000; Bowler & Thommen, 2000; Klin, 2000; Schultz et al., 2003; Castelli, Frith, Happé, & Frith, 2002). Castelli et al. (2002) used these stimuli for an fMRI investigation and their findings revealed reduced activation of the mentalising network (medial prefrontal cortex, superior temporal sulcus at the temporo-parietal junction and temporal poles) in subjects with autism compared to typical subjects. Schultz et al. (2003) used the same task and found activation of the FFA, together with the amygdala, temporal pole, medial prefrontal cortex, inferolateral frontal cortex and superior temporal sulci, suggesting that the importance of this finding for autism is in showing that the FFA has a role in the broader social network and this role is dependent on its functional relationship with other regions within the social brain. The last statement is supported by finding of a strong correlation between FG and amygdala activation in this study. This finding suggests that various nodes of social brain are interconnected could clarify pathobiology of autism and particularly social difficulties in autism.

2.4.2. Superior temporal sulcus (STS)

The superior temporal sulcus (STS) has an important role in social cognition and because of this importance is characterised as "a node of social brain" (Pelphrey & Carter, 2008, p. 6). It has the major role in an aspect of the social brain that is referred as "social perception" (Zilbovicius et al., 2006). Social perception represents an initial stage of evaluating intentions and goals of others from various types of biological motion, such as eye-gaze direction, body movements and facial expressions (Allison, Puce, & McCarthy, 2000; Redcay, 2008). This region is implicated in various studies examining face perception, as faces represent a complex form of biological motion with facial muscles changing over time for particular emotions (Redcay, 2008). Haxby et al., (2000, 2002) proposed a model of face processing that prescribes the main role in this model to processing of dynamic components of the face, such as direction of gaze, mouth movements, and facial expressions. In contrast, the FFA is involved in processing of facial identity as representing invariant aspects of faces.

The STS is also involved in visual perception of human bodies (Downing, Jiang, Shuman, & Kanwisher, 2001; Kontaris, Wiggett, & Downing, 2009), body movement (reviewed in Allison et al., 2001), and biological motion (Beauchamp, Lee, Haxby, & Martin, 2003; Grossman & Blake, 2002; Pelphrey et al., 2003). Biological motion refers to the visual perception of any movement representing a biological entity performing recognisable movements (Pelphrey & Carter, 2008). Biological motion can be depicted by point-light displays, that is, stimuli that are created by attaching small lights to the joints of a person and then filming various actions performed by the person. The STS was found to be activated for point-light displays of movements of body, hands, face, and eyes (Zilbovicius et al., 2006), but not when viewing random motion of lights (Bonda, Petrides, Ostry, & Evans, 1996). Activation of the posterior STS is particularly increased by attributing intentions or "mentalising" to moving objects (e.g., Materna, Dicke, & Thier, 2008; Schultz, Imamizu, Kawato, & Frith, 2004; Spiers & Maguire, 2006).

The STS receives an input from both form and motion of the stimuli and integrates them to form a meaningful and intentional action with a social significance (Redcay, 2008). The greatest response in the STS is found for motions that are more complex and socially meaningful and relevant (Zilbovicius et al., 2006). For example, greater activation in the STS was found for physically possible movements than for impossible movements (Zilbovicius et al., 2006). This shows that the STS is not activated by just perceptual aspect of stimuli, but by its meaningfulness and its contribution to social communication (Zilbovicius et al., 2006). Pelphrey et al. (2005b) showed that different types of biological motion, such as eyes, mouth and hand movements, are differentially distributed along the STS region.

2.4.2.1. STS in autism

Individuals with autism show structural and functional abnormalities within the STS. Several voxel-based morphometry studies showed that adults with ASD have different grey matter volumes through frontal and temporal brain regions compared to neurotypical adults (Abell et al., 1999), and that children with ASD in comparison to neurotypically developing children showed decreased concentrations of grey matter localised bilaterally to the STS (Boddaert et al., 2004). A study (McAlonan et al., 2005) also showed reduction of grey matter in the fronto-striatal, parietal, and temporal cortex in children with high functioning autism, indicating that structural abnormality of the "social brain" is already present in early childhood. Reduced grey matter volume has been also reported in the STS (Hadjikhani et al.,

2006; Hyde, Samson, Evans, & Mottron, 2010; Wallace, Dankner, Kenworthy, Giedd, & Martin, 2010), which correlated significantly with autism symptoms (Hadjikhani et al., 2006). In addition to previous studies, post-mortem studies of autism brains showed temporal lobe abnormalities (e.g., Bailey et al., 1998b).

Individuals with autism also display atypical neural activity in the STS during processing of social tasks, as indicated by functional imaging studies. Differences between autistic subjects and healthy controls were found in face processing studies. For example, differences in the activation of the cerebellum, the mesolimbic, and temporal lobe cortical regions during explicit and implicit processing of facial expressions were found in autistic groups (Critchley et al., 2000), and reduced STS, amygdala and FFA were found in autistic subjects when viewing neutral facial expressions (Pierce et al., 2001). In an fMRI study, Pelphrey, Morris and McCarthy (2005a) examined the STS activation during observation of eye gaze shifts in individuals with autism and a healthy control group. Participants observed a face that made an eye gaze shifts in the direction of the flickering checkerboard, with the eye gaze shifted towards the checkerboard (congruent task), or towards an empty corner of the screen with no checkerboard (incongruent task). Results showed that although both groups showed activation of the STS and other brain structures typically implicated in social cognition and theory of mind to shifts of eye gaze, the typical group but not autistic group showed brain differentiation for congruent and incongruent gaze shifts. While typical participants showed greater right STS activation to incongruent than to congruent gaze shifts, this differential activation of the STS was absent in autistic participants. As incongruent gaze shifts convey intentional and mind reading attributes, it is suggest that individuals with autism do not have problems in eye gaze discrimination, but have difficulties in using eye gaze for recognising intentions and thinking about other minds (Pelphrey et al., 2005a).

The STS was also found to be activated by actions that require making inferences about mental states in a task that used moving triangles (Heider & Simmel, 1994). In this study, Castelli et al. (2002) asked participants to recognise intentions in stimuli with various geometric shapes that through their movements can appear to show an intention (following one another) or theory of mind ability (coaxing and tricking one another). During the presentation of these animations, individuals with autism in comparison to typical controls showed less activation in various brain regions, including the STS. Reduced functional connectivity between the STS and the extrastriate region of the occipital cortex was found in autism groups, suggesting that difficulties in mentalising found in autism may have a source in disrupted connectivity between regions within the larger social brain network. Castelli et

al. (2002) suggest that the reduction in connectivity between the visual cortex and the STS might reflect a failure of top-down modulation by regions such as the amygdala, which typically enhance attention to socially relevant stimuli (Adolphs, 2003).

2.4.3. Amygdala

The amygdala is another brain structure thought to comprise the "social brain" network. It is a complex structure consisting of at least 13 nuclei located in the anterior medial temporal lobe (Pelphrey, Adolphs, & Morris, 2004). One of its main functions is considered to be modulation of incoming sensory information from other regions of the social network, particularly the FFA and STS, and prescribing emotional and motivational value to stimuli (Adolphs, 2003; Grelotti et al., 2002; Neuhaus, Beauchaine, & Bernier, 2010). The amygdala is involved in face processing and has a key role in emotional processing, particularly processing of fearful and threatening stimuli (Adolphs et al., 1999, 2005; Adolphs, Tranel, Damasio, & Damasio, 1994, 1995; Calder, Lawrence, & Young, 2001; LeDoux, 2000; Rodrigues, Schafe, & LeDoux, 2004). It is also involved in other facial signals of threat or danger. For example, greater amygdala activation was found in response to viewing pictures of faces rated as untrustworthy (Adolphs, Tranel, & Damasio, 1998; Engell, Haxby, Todorov, 2007; Todorov, Baron, & Oosterhof, 2008; Winston, Strange, O'Doherty, & Dolan, 2002), and patients with amygdala damage rated as more trustworthy pictures of faces that were rated as untrustworthy by healthy controls (Adolphs et al., 1998). However, recent studies have shown that it is also involved in the processing of positive emotions (Baxter & Murray, 2002; Holland & Gallagher, 2004), and even electrophysiological studies with primates have indicated amygdala activation to various emotions (Rolls, 2000b). A study showed that subjects with amygdala damage are impaired in their recognition of complex social emotions such as arrogance, but not in recognition of basic emotions (Adolphs, Baron-Cohen, & Tranel, 2002). Some studies showed that amygdala is also activated by social and emotional information from non-social stimuli. Haberlein and Adolphs (2004) showed to patients with amygdala damage the previously mentioned Heider and Simmel's (1944) animations - videos of different geometric shapes showing interactions that can be interpreted as goal directed and social. The study showed that the patients with amygdala damage differed from healthy controls by not prescribing any social or motivational motives to moving geometric shapes.

The amygdala is extensively connected with many brain regions, including the neocortex, hippocampus, brainstem, thalamus, and basal forebrain (Pelphrey et al., 2004). Recent research has pointed out that the amygdala is structurally and functionally interconnected with many regions of the medial prefrontal cortex (MPFC), in particular with the orbital cortex and anterior cingulate cortex (review in Whalen et al., 2013; Freese & Amaral, 2009; Ghashghaei, Hilgetag, & Barbas, 2007). A hypothetical role of the MPFC is in regulating and controlling amygdala output as a top-down control (e.g. Bishop, 2007; Morgan, Romanski, & LeDoux, 1993; Ochsner & Gross, 2005). Studies on bottom-up and top-down processing in emotion research have examined both the amygdala and MPFC separately (Bishop, 2007), but it is suggested that a better understanding could be obtained by examination of the structural and functional connectivity between the amygdala and prefrontal cortex (Kim, Gee, Loucks, Davis, & Whalen, 2011; Kim & Whalen, 2009). In emotion research, bottom-up processing is driven by the characteristics of stimuli, and top-down processing integrates contextual information that influences the meaning of the situation (Whalen et al., 2013).

2.4.3.1. Amygdala in autism

Baron-Cohen et al. (2000) developed the amygdala theory of autism based on observed abnormalities of amygdala in autism, although implications of amygdala in autism were recognised much earlier (Bachevalier, 1991). Bachevalier (1991) suggested an animal model of childhood autism, based on findings (Bachevalier & Mishkin, 1989) that infant monkeys showed socio-emotional abnormalities similar to those seen in autistic children as a consequence of combined bilateral neonatal ablations of the amygdala, hippocampus, and overlying cortices. Evidence for abnormal amygdala in autism is based on post-mortem studies of the brains of people with autism that showed microscopic pathology in the amygdala and similarities between autism and patients with amygdala lesions who show impairments in social judgments (Kemper & Bauman, 1998). Structural abnormalities were also found in autism, indicating reduced amygdala volume in this group (Abell et al., 1999). In contrast, increased amygdala volume was also found (Howard et al., 2000) as an indicator of sub-optimal operation of the structure, which suggests that it is a cause of impairment in social perception in autism. Social impairments in this study were related to impaired identification of fearful facial expressions, eye-gaze direction and facial recognition memory. However, a recent study did not find any differences between children with autism and

typical controls in the volume of the right or left amygdala (Corbett et al., 2009), suggesting a need for further examination of amygdala dysfunction in autism. Functional studies of the amygdala in autism also indicated abnormal brain connections during face processing, with impaired functional connectivity between the FFA and amygdala, with poorer connectivity in individuals who were more socially impaired predicting clinical severity (Kleinhans et al., 2008).

The amygdala may be important for normal development of social cognition and social behaviour, as amygdala lesions early in life leads to deficits related to theory of mind in humans and social play behaviour in animals, whereas lesions sustained later in life do not (Daenen, et al., 2002; Shaw et al., 2004). This developmental course of structure and function of the amygdala and its influence on social cognition still needs examination in autism. Differences between children with autism and typical controls can be seen in developmental changes of amygdala volume, with initially larger amygdala in children with autism, but with no age-related increase found in typically developing children (Schumann et al., 2004). This finding is further supported by a study that used stereological measurement of post-mortem brains of adult males with autism, revealing a reduced number of neurons in the autistic amygdala (Schumann & Amarall, 2006). In sum, those studies suggest that the amygdala in autism goes through an enlargement early in development that is followed by a reduced number of neurons later in development.

In one of the first fMRI studies that showed abnormalities in the amygdala in autism, Baron-Cohen et al. (1999) used the Judging the mind in the eyes task, a metalising task that requires recognition of complex emotional states from isolated eyes. This study showed absent amygdala activation in adults with high functioning autism or Asperger Syndrome for the theory of mind task, and also less activation of the frontal regions compared to the neurotypical control group. However, the autism group showed greater responses in bilateral superior temporal gyrus (STG), and Baron-Cohen et al. (1999, 2000) suggest that this area was activated by autistic subjects as compensation for absent amygdala activation. The healthy control group showed greater activation in the left amygdala during metalising, suggesting an importance of this area for identifying mental states and emotions from eye information. However, a recent study (Dziobek, Fleck, Rogers, Wolf, & Convit, 2006) suggested a need for re-examination of the role of the amygdala in autism, based on the new findings that found associations between social and emotional reasoning and amygdala volume in neurotypical individuals, but not in autistic individuals. Instead, this study showed

that in the autistic group, amygdala volume was associated with restrictive-repetitive behaviour, possibly having a function of inhibiting restrictive-repetitive behaviours.

Several fMRI studies that examined amygdala function in autism have indicated that amygdala is hypoactivated in autism (Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2008; Bookheimer, Wang, Scott, Sigman, & Dapretto, 2008; Corbett et al., 2009; Hadjikhani et al., 2007), but several others have indicated that is it hyperactivated (Dalton et al., 2005; Monk et al., 2010; Tottenham et al., 2013; Weng et al., 2011;). Swartz et al. (2013) explained the differences in these findings by the differences of presentation times of stimuli. Studies that found hypoactivation of amygdala in autism used longer presentation times that allowed individuals with autism to attend away from stimuli, as this group is less attentive to faces in general. On the other hand, amygdala hyperactivation was found in studies with shorter presentation times that reduced group differences in attention to faces. However, findings of intact amygdala function in autism (e.g., Bernier, Dawson, Panagiotides, & Webb, 2005; Dziobek et al., 2006; Grelotti et al., 2005; Pierce, Haist, Sedaghat, & Courchesne, 2004) can be explained by complexity of the amygdala, which is involved in numerous functions and contains many distinct nuclei, and not all of them may be impaired in autism (Ashwin et al., 2006; Pierce et al., 2004). Furthermore, various models of amygdala dysfunction in autism suggest atypical amygdala functioning, but not a complete absence of amygdala function (Ashwin et al., 2006; Baron-Cohen et al., 2000a; Schultz, 2005).

A study that used face inversion tasks found reduced inversion effect in children with autism compared to typically developing children (Bookheimer et al., 2008). In this study, differences between groups were not found in the FFA, but rather in the frontal cortex and the amygdala, suggesting that the decreased inversion effect in autism appears to reflect differences in processing the social significance of faces rather than perceptual information of the stimuli. Amygdala activity was also found to be reduced during implicit emotion discrimination (Critchley et al., 2000), and tasks of complex social cognition such as judging the trustworthiness of faces (Pinkham et al., 2008). A recent study also pointed out that the amygdala is implicated in the development of mentalising in autism (Shaw et al., 2004). Some studies showed that activation of amygdala in participants with autism is modulated by the time spent attending to the eyes (Dalton et al., 2005) and familiarity of faces (Pierce et al., 2004), with significant amygdala activity in response to familiar faces that are also personally meaningful, but no significant activity in response to stranger faces. Because the amygdala is crucial for assigning emotional significance to stimuli, amygdala dysfunction can lead to an impaired ability to find significance in emotional stimuli and/or to use them for guiding social

behaviour (Ashwin et al., 2007; Critchley et al., 2000; Neuhaus et al., 2010). Adolphs, Sears and Piven (2001) examined social information processing from faces in individuals with autism by using tasks similar to those used in their previous study with individuals with bilaterally damage. Results indicated normal perceptual discrimination of faces, but abnormal social judgements of trustworthiness from faces in individuals with autism. Similar results were obtained in patients with bilateral damage, and the authors concluded that amygdala dysfunction in autism might contribute to an impaired ability to link visual perception of socially relevant stimuli with social behaviour.

2.4.4. Structural neuroimaging abnormalities of social cognition in autism

An additional explanation is needed regarding structural abnormalities found during face processing in individuals with autism. Structural abnormalities in autism are not easy to interpret because of mixed results about grey and white matter volume in different regions. Discrepancies in findings can be a result of different methods used for assessing grey and white matter volume in the brain, such as more recent diffusion tensor imaging (DTI) (e.g., Anagnostou & Taylor, 2011; Bloemen et al., 2010; with a detailed review of DTI in Thomason & Thompson, 2011). Even more important for explaining different results are age differences of subjects as age-related structural abnormalities in the brain of individuals with autism have been indicated in many previous studies (Courchesne, Campbell, & Solso, 2010; Doyle-Thomas et al., 2013; Schumann et al., 2010). An atypical developmental trajectory of neurodevelopment in autism consists of rapid abnormal growth in early childhood that is followed by a plateau in growth considered to be a possible a phase of degeneration, resulting in slightly smaller brains than in typically developing controls (Courchesne et al., 2010). Although many structural neuroimaging studies show abnormalities in major regions implicated in social cognition and face perception described previously, namely, FFA, STS and the amygdala, it is difficult to say how those impairments are related to social cognitive processes. It is also possible that, as structural examination of autistic brains show specific age related changes, it is possible that better understanding of age related structural changes of each of those regions would give a better understanding of social impairments in autism and the importance of particular regions in it.

2.5. Emotion and consciousness

When we navigate through the world our sensory systems are not able to process all information and therefore we need to evaluate them and select those that may be the most important. Our brain possesses mechanisms that are generally related to selective attention, which allow the brain to choose the most salient or relevant information among competing stimuli (Vuilleumier, 2005). Many behavioural studies have indicated that our attention is drawn more towards emotional than neutral stimuli. For example, in a visual search task that requires finding a target among distractors, the target is found faster when it has some emotional value, such as emotional facial expressions among neutral faces, in particular fearful and happy faces among neutral faces (Fox, 2002) and threatening faces (Eastwood, Smilek, Merikle, 2001; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Those effects were observed even for schematic faces (Öhman, Lundqvist, & Esteves, 2001). These findings suggest that under conditions of attentional constraint, emotional information gets priority in access to attention or awareness (Vuilleumier, 2005). It is generally considered that more biologically salient stimuli, such as faces and negative or threatening information, are processed by a dedicated system that operates rapidly, automatically and without attention and even without conscious awareness (Tamietto & de Gelder, 2010). Supporting the view that the amygdala is specialised for the rapid detection of emotionally relevant stimuli and that this can occur without attention or awareness, Vuilleumier, Armony, Driver and Dolan (2001) used an fMRI study to examine attention to faces or houses presented eccentrically while subjects fixated a central cue. Results showed that the amygdala was not modulated by attention regardless of stimulus valence, whereas attention increased activity in the fusiform gyrus. Several other studies have indicated that task-irrelevant fearful faces are processed independently of attention (e.g., Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Williams, McGlone, Abbott, & Mattingley, 2005).

Facial expressions are socially significant stimuli and, based on that, their processing is considered to be privileged and may take place independent of awareness (Adolphs, 2002; Hsu, Hetrick, & Pessoa, 2008). Neuroimaging studies have implicated the amygdala in facial emotion processing, particularly processing of fearful facial expressions, even when they are presented so quickly that subjects are unaware of them (Whalen et al., 1998; Whalen et al., 2004; Morris, Öhman, & Dolan, 1998b, 1999) or are presented in the blind hemifield of patients with blindsight (Morris, DeGelder, Weiskrantz, & Dolan, 2001).

However, not all studies have supported independence of emotional stimuli from attention or awareness. For example, in contrast to previously described findings, some research studies have suggested that processing of emotional stimuli, in particular emotional faces, is modulated by attention when the main task is demanding (e.g., Holmes, Vuilleumier, & Eimer, 2003; Holmes, Winston, & Eimer, 2005; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005). Pessoa et al. (2002) used two tasks, one in which participants were asked to recognise gender of the face stimuli (attended trials) and a task in which they were asked to recognise whether bars, positioned in a corner of the screen together with face stimuli, were of similar or different orientation (unattended trials). The task that did not ask for attention towards faces was considered to compete for attention with face stimuli and therefore to be more demanding than tasks in other studies that examined the amygdala activation and attention to faces. Pessoa et al. (2002) not only found greater activation of the amygdala for attended faces, indicating that emotional processing in the amygdala is susceptible to top-down control, but also showed that all brain regions typically activated by faces, including the fusiform gyrus, required attention. Differences in studies about activation of the amygdala in an aware and unaware condition probably can be explained by task differences and need further and more careful investigation.

The amygdala is found to be involved in both conscious and non-conscious processing of fearful stimuli (Calder, Lawrence & Young, 2001). However, it can be argued that not only the amygdala, but also other brain regions linked to emotion processing, are often subcortical, such as the nucleus accumbens, ventral striatum and hypothalamus (Berridge, 2003; LeDoux, 1996; Pessoa, 2008). Recently, many studies have started to investigate the subcortical route for face processing, and it has been proposed that the subcortical visual pathway that enables rapid processing is already functioning at birth and may be responsible for recognition of faces in newborns (Grossmann & Johnson, 2007; Johnson, 2005).

Support for the subcortical route for processing of emotional stimuli has been shown in research studies involving healthy participants, and also lesion studies. Findings about subcortical emotion processing can be found in studies that examine perceptual processing of images with different spatial frequency components. Those studies typically divide spatial frequencies in two groups: higher spatial frequencies (HSFs) (which depict greater details of faces) and lower spatial frequencies (LSFs) (which depict more global level features and general configuration of faces) (Johnson, 2005). Those different frequencies are processed by different neural pathways. Thus, the HSFs are carried to the cortical ventral visual stream

mainly by **parvocellular** channels (Livingstone & Hubel, 1988; Merigan & Maunsell, 1993). This pathway shows greater detail of the stimuli, but with slower response (detailed review of these two pathways are given in Johnson, 2005). The LSFs are carried by **magnocellular** channels to the superior colliculus and pulvinar (Schiller, Malpeli, & Schein, 1979). Magnocellular pathway is characterised by a rapid system of visual processing that is particularly involved detecting threatening stimuli (Johnson, 2005; Tamietto & de Gelder, 2010). In contrast, parvocellular pathway is characterised by a slow system of visual processing. A detailed representation of cortical and subcortical pathways involved in visual and emotion processing is shown in **Figure 2-2.**

Several fMRI studies with typical adults have found activation of the fusiform cortex to HSF information about faces, whereas LSF information about faces, particularly fearful faces, activated the **subcortical route** consisting of the pulvinar, amygdala and superior colliculus (Vuilleumier, Armony, Driver, & Dolan, 2003).

Research support for unconscious processing of emotional faces has also been found in studies with cortically blind patients (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999). De Gelder et al. (1999) reported a case of the patient GY with blindsight (patients with striate cortex lesions, Weiskrantz et al., 1974) who was able to discriminate facial emotional expressions in the blind visual field without acknowledged awareness of the faces. The authors ascribed the capability of GY's discrimination of unaware facial expressions to his intact projection from the retina to the cortex through the superior colliculi (SC). Similarly, Pegna, Khateb, Lazeyras and Seghier (2005) reported correct recognition of unconscious emotional (angry and happy) faces by a subject with a recent bilateral destruction of the visual cortex. In this study, unconscious perception of emotional faces showed significant right amygdala activation. Recognition of subliminally presented schematic emotional faces (sad and happy) was found in a study (Jolij & Lamme, 2005) with healthy participants whose awareness was blocked by the application of transcranial magnetic stimulation (TMS) over the primary visual cortex. Participants showed correct discrimination of facial expressions reflecting subliminal processing of expressions through the superior colliculus pathway.

Figure 2-2: Cortical and subcortical pathways for vision and emotion processing (reproduced from Tamietto and de Gelder, 2010, p. 4):
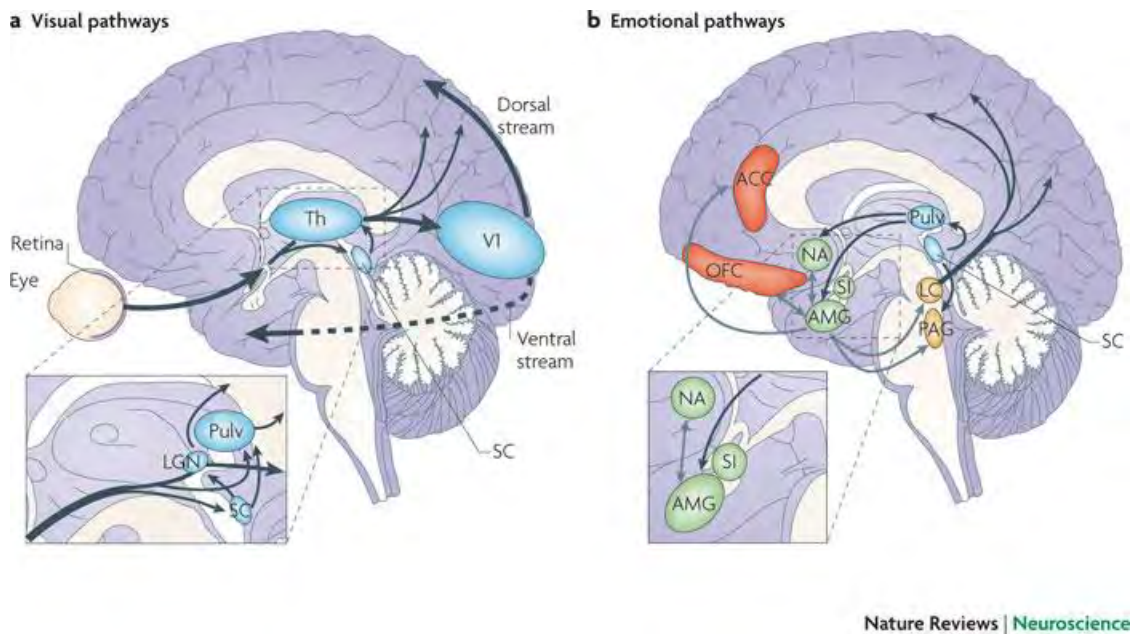
a) The primary visual pathway (shown by thick arrows) originates from the retina and projects to the primary visual cortex (V1) through the lateral geniculate nucleus (LGN) of the thalamus (Th) (to the primary visual (striate) cortex). From V1, visual information reaches two extrastriate cortical pathways: the ventral (occipitotemporal) and the dorsal (occipitoparietal) stream. However, a minority of fibres extending from the retina move through a secondary route (shown by thin arrows) and reach both the superior colliculus (SC) and the pulvinar (Pulv). These two subcortical sites send direct projections to the extrastriate visual cortex, bypassing V1. Another visual pathway that also bypasses V1 is through the direct projections between the superior colliculus and the LGN that, in turn, projects to extrastriate cortices in the dorsal stream (Tamietto & de Gelder, 2010). The "ventral" streams, extends into the temporal lobe and is predominantly involved in visual object recognition. The "dorsal" stream extends into the parietal lobes and is primarily involved in extracting information about "where" an object is or "how" to perform visually guided actions towards it (Wurtz, & Kandel, 2000).

b) Non-conscious perception of emotional stimuli is processed by subcortical structures including the superior colliculus (SC), the visual pulvinar (Pulv), the amygdala (AMG), the substantia innominate (SI; shown in green) and the nucleus accumbens

(NA). The amygdala (AMG) and the substantia innominata (SI; shown in green) are buried deeply in the temporal lobe and in the basal forebrain, respectively. The nucleus accumbens (NA) is buried in the basal ganglia (shown in green) and brainstem nuclei (shown in yellow). Cortical areas (shown in red) include the orbitofrontal (OFC) and the anterior cingulate cortex (ACC). The visual and emotional systems are extensively interconnected, especially at the subcortical level, where the superior colliculus is connected to the amygdala via the pulvinar (Tamietto & de Gelder, 2010).

Several studies have found emotion discrimination in healthy brains for various facial expressions (e.g., fear, disgust, and happiness) by using various techniques, such as backward masking (e.g., Kiss & Eimer, 2008; Pegna, Landis, & Khateb, 2008; Smith, 2011; Williams et al., 2006), binocular rivalry (e.g., Pasley, Mayes, & Schultz, 2004; Williams, Morris, McGlone, Abbott, & Mattingley, 2004), Continuous Flash Suppression (e.g., Tsuchiya & Koch, 2005; Jiang & He, 2006; Jiang, et al., 2009; Willenbockel, Lepore, Nguyen, Bouthillier, & Gosselin, 2012) or reduced attention (Vuilleumier et al., 2001; Anderson et al., 2003). This brief review will mostly focus on the backward masking paradigm.

Neuroimaging support for a subcortical route for facial emotion processing can be found in several studies that used backward masking paradigms developed by Öhman et al. (Esteves & Öhman, 1993) to examine amygdala activation during the processing of non-conscious facial expressions. Backward masking is a popular technique for investigating perceptual processing without awareness (Esteves & Öhman, 1993; Maxwell & Davidson, 2004). It entails a brief presentation of target stimuli, usually a face, which is masked by a following image (typically a neutral face or various non-face pattern masks), which disrupt processing of the target image by preventing reaching conscious awareness (Esteves & Öhman, 1993; Maxwell & Davidson, 2004). It is thought that the masking stimulus interrupts the re-entrant processing of the target stimulus in the sensory cortex, restricting the initial representation (Enns & Di Lollo, 2000). For example, Whalen et al. (1998) found significantly larger fMRI signals in the amygdala during viewing of backward masked fearful faces compared to happy faces. Combining backward masking with classical conditioning, Morris et al. (1998a) investigated responses to conscious and non-conscious angry faces, and revealed that the right amygdala was activated by the contrast of conditioned and non-conditioned un-aware angry faces. The backward masking paradigm was used in various

electroencephalographic (EEG) and event-related potential (ERP) procedures that are able to provide better timing of unconscious emotion processing. The earliest differentiation between fearful and neutral facial expressions was found already within a 140-180 ms time window over anterior (Kiss & Eimer, 2008) or temporal electrodes, particularly on the N170 component (Pegna et al., 2008). However, some other studies reported later differentiation between fearful and neutral faces for the N200 component (Liddell et al., 2004).

However, several studies of subliminal face perception have found activation in the human cortex, denying activation of subcortical structures by subliminally presented faces. For example, in an fMRI study with a subliminal masked face priming paradigm, Kouider, Eger, Dolan and Henson (2009) found activation in cortical, face-processing structures (see also de Gardelle & Kouider, 2010; Dolan et al., 1996). The differences in results are likely explained by the use of attention rather than in attention as a measure. An ERP study also showed that facial expression processing depends on stimulus visibility with no priming effects observed for emotional stimuli presented in the low-visibility condition (Hsu, Hetrick, & Pessoa, 2008).

Impairment in unconscious processing in autism may be explained by the important role played by the amygdala in the unconscious processing of social stimuli, including gaze (Whalen et al., 2004). Although it is not yet clear how automatic processes emerge, it is suggested that they could derive from either heredity or practice (Hasher & Zacks, 1979). Individual differences at the genotypic and personality level have been indicated in processing of non-conscious stimuli (Öhman & Mineka, 2001; Lonsdorf et al., 2009).

The spatial frequency processing of faces in autism has been mostly investigated in relation to its atypical perceptual-cognitive information processing as described by the "weak central coherence" hypothesis (Frith & Happé, 1994; Happé & Frith, 2006; Hill & Frith, 2003) and by many studies that have reported superior processing of local level details in autism (e.g., Behrmann et al., 2006; Jolliffe & Baron-Cohen, 1997; Happé, 1996; Plaisted, Swettenham, & Rees, 1999; Shah & Frith, 1993). It is proposed that face perception depends both on perceiving individual facial features (such as eyes, nose and mouth) and their configurations (Maurer, Le Grand, & Mondloch, 2002). Several studies employing spatial frequency as a condition have examined the role of global vs. local level facial details in configural processing (Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffaux & Rossion, 2006). These have indicated that configural processing of faces is dependent predominantly

on global facial features. Spatial frequency studies of subjects with autism have provided further support for the primacy of local over global processing in autism (e.g., Curby, Schyns, Gosselin, & Gauthier, 2003; Deruelle, Rondan, Gepner, & Tardif, 2004). Studies also indicated difficulties in emotion processing from LSF (global shapes of face images without local features) (Kätsyri, Saalasti, Tiippana, von Wendt, & Sams, 2008) in adults with ASD, and relying more on HSF for categorisation of both facial identity and emotions in children with ASD compared to typical children. Results of this study showed difficulties in recognising facial emotions from low-spatial frequencies in subjects with autism, along with normal emotion recognition from static and dynamic facial stimuli. This finding indicates impaired visual processing of global features in the ASD group. Although those studies with spatial frequencies in autism have not examined the subcortical route in emotion processing, results give support for further investigation of the subcortical route in the disorder based on previous studies that indicated that non-conscious processing of faces rely on LSF (e.g., Willenbockel, Lepore, Nguyen, Bouthillier, & Gosselin, 2012).

Impairment of unconscious processing of social information has been found in autism. For example, Sato, Uono, Okada and Toichi (2010) showed impairment in unconscious but not conscious joint attention in individuals with Asperger's disorder. Previous studies have indicated deficits in joint attention as the one of the most important features of social impairment in the disorder (Mundy, Sigman, & Kasari, 1994). Joint attention is an ability to shift attention when following another's gaze. However, not all studies found impairments in joint attention in autism (e.g., Chawarska, Klin, & Volkmar, 2003; Johnson, 2005). A previous study with typical individuals showed that gaze-triggered attention could occur both consciously and unconsciously, giving them two mechanisms for successive automatic joint attention (Sato, Okada, & Toichi, 2007). In contrast, individuals with autism can achieve this only through conscious processing of gaze (Sato et al., 2010). However, Sato et al. (2010) suggested that although people with autism may have "innate impairments in the unconscious subcortical system", they are still capable of acquiring through practice the conscious cortical system that allows joint attention (Sato et al., 2010, p. 786).

Joint attention is particularly important for explaining social impairments in autism. As joint attention represents understanding and appreciating people's point of view (Sigman, Ungerer, Mundy, & Sherman, 1986), it would suggest that this understanding is impaired in people with autism. However, although it has similarities with the theory of mind or mind-reading, it is of much earlier developmental origin than theory of mind. Whereas theory of

mind is present in 3-4 year old typical children, joint attention is well-developed by 14 months of age (Scaife & Bruner, 1975; Butterworth, 1991). Thus, absent joint attention in autism indicates that it is a deficit that is present very early in a child's development (Baron-Cohen, 2001b). Baron-Cohen (1989c, d, 1991b) proposed that joint attention was a precursor to the development of mind-reading. Similar to this idea, Bretherton, McNew and Beeghly-Smith (1981) had proposed joint attention to be understood as an "implicit theory of mind". This proposal suits Baron-Cohen's (2001b) idea of joint attention as an "implicit awareness of the mental", complementing his idea of autism as "lacking the normal consciousness of the mental" (Baron-Cohen, 2001b, p. 69), as explained by the mindblindness hypothesis (Baron-Cohen, 1990, 1995).

Diminished attention to faces are seen already in the first months of life in autistic children (Maestro et al., 2002), and Schultz (2005) proposed that this could stem from congenital abnormality of the subcortical system, probably involving mostly the amygdala. This suggestion is based on Morton and Johnson's (1991) hypothesis of a subcortical mechanism that influences face preferences observed in typical newborns (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Simion, Valenza, Umilta, & Dalla Barba, 1998; Slater & Quinn, 2001; Valenza, Simion, Cassia, & Umilta, 1996). According to Schultz's proposal, congenital abnormality of the amygdala in autism could lead to a failure to "orient to salient social stimuli such as faces, and would preclude the development of the type of face expertise mediated by the FFA" (Schultz, 2005, p. 134).

There are several, mostly fMRI, studies that have examined subliminal emotion processing in autism by using a backward masking paradigm. Hall et al. (2007) examined the effect of backward masking of neutral and anxious faces on the social decisions of a group of high functioning children with autism and matched controls. Their results indicated that the social choices of children with autism were influenced less by emotional information presented subconsciously, suggesting a subcortical contribution to the social/emotional processing deficit observed in autism. In another fMRI study, Hall et al. (2010) examined sub-threshold processing of anxious faces in high functioning adult males with autism and a matched control group. They found heightened neural activation of the amygdala in both groups, but adults with ASD showed significantly lower levels of fusiform activation compared to controls. They suggested that in autism the transmission of socially salient information along subcortical pathways is intact, but the signalling of this information to structures downstream may be impoverished, and the pathways that facilitate subsequent

processing are deficient. Using the same paradigm to examine emotion processing in adults with autism, Kleinhans et al. (2011) found that individuals with autism activated the fusiform gyri during processing of fearful faces, whereas the healthy controls activate fusiform and subcortical structures (pulvinar, superior colliculi, and amygdala). Fusiform gyri are suggested to have an important role in processing facial identity, and pulvinar, superior colliculi and amygdala in emotion processing (Klenhans et al., 2011; Johnson, 2005). Kamio, Wolf and Fein (2006) used an affective priming task in which they presented individuals with high functioning Pervasive Developmental Disorders (HFPDD) and typical individuals as a control group with primes consisting of pictures of happy and fearful faces and objects in subliminal and supraliminal conditions. Results revealed an absence of affective priming by pictures of emotional faces in individuals with HFPDD, whereas control groups showed affective priming for facial expressions. The absence of affective priming was associated with amygdala dysfunction and its importance in evaluating and assigning stimuli as socially or biologically significant. Together, findings about subcortical processing of facial emotional expressions can give important insights into emotion processing deficits in autism.

2.6. Is magnocellular function atypical in autism?

Although research on visual processing deficits in autism is very inconsistent, with some studies ascribing them to basic perceptual factors, in particular to low-level visual difficulties, while others ascribe them to higher level deficits involving socio-cognitive and attentional mechanisms. Magnocellular impairment in autism has been supported by findings of impaired processing of transient or rapidly moving stimuli in this disorder (e.g. Gepner & Mestre, 2002; Greenaway, Davis, & Plaisted-Grant, 2013; Greenaway & Plaisted, 2005; Milne et al., 2002; Spencer et al., 2000), along the lines of previous mentioned findings of a bias towards processing of high- rather than low-spatial frequencies in face and emotion processing tasks in autism (e.g. de Jong, van Engeland, & Kemner, 2008; Deruelle, Rondan, Salle-Collemiche, Bastard-Rosset, & DaFonséca, 2008; Kätsyri, Saalasti, Tiippana, von Wendt, & Sams, 2008; Vlamings, Jonkman, & Kemner, 2010). Based on the subcortical route to face processing (Johnson, 2005), atypical magnocellular input into this pathways would impair social information processing, including face processing, in people with autism. Evidence for atypical magnocellular function in autism is mostly indirect, based on studies of elevated global motion coherence thresholds in autism (Greenaway et al., 2013; Milne et al., 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Spencer et al., 2000), and also

based on recent evidence of impaired subcortical routes to face processing in autism (e.g., Kleinhans et al., 2011). Some studies suggest that this impairment is present mostly in a subgroup of autism, probably in lower functioning individuals. Direct support is found in Sutherland and Crewther's (2010) nonlinear VEP study showing atypical second order kernels in neurotypical adults with high Autism Spectrum Quotient (AQ) scores previously related to magnocellular processing on the basis of contrast gain, contrast saturation and latency.

As autism is a developmental disorder, findings exploring the developmental trajectories of the magnocellular and parvocellular pathways also suggest the importance of the subcortical pathway for explaining social and emotional difficulties in autism (e.g., Hammarrenger et al., 2003). Previous evidence of the earlier development of the magnocellular pathway than the parvocellular pathway (Dobkins, Anderson, & Lia, 1999; Hammarrrenger et al, 2003), suggest that early magnocellular impairment in autism could lead, among others, to bias towards processing HSF information during facial emotion processing (Deruelle et al., 2008; Vlamings et al., 2010). Braddick, Atkinson and Wattam-Bell (2003) suggested the dorsal visual stream vulnerability during development, based on findings of difficulties in detection of motion coherence in a field of dots, a finding observed not only in development of people with autism, but in other developmental disorders including Williams syndrome (Atkinson et al., 2005; Braddick et al., 2003; Grinter, Maybery, & Badcock, 2010; Spencer et al., 2000). However, evidence against a magnocellular deficit is also found (e.g., Davis, Bockbrader, Murphy, Hetrick, & O'Donnell, 2006; Koh, Milne, & Dobkins, 2010; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005).\

2.7. Mirror neuron system (MNS)

Mirror neurons are premotor neurons activated by the observation of an action performed by another person and when the action is executed (Gallese, 2009; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Fogassi, & Gallese, 1996). This direct mapping of action perception and execution is defined as the Mirror Neuron System (MNS) (Gallese, 2003a, 2003b, 2006; Gallese, Keysers, & Rizzolatti, 2004; Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2001). fMRI studies with humans have extended the network of neural regions that are now known as the MSN. This area in the macaque brain encompasses area F5c of the inferior frontal cortex (Rizzolatti & Craighero, 2004) and the rostral inferior parietal cortex (Fogassi & Luppino, 2005). Although initially it was difficult

to find the source of the visual input of area F5, it has been found that the major visual input is from the inferior parietal lobule (Cavada & Goldman-Rakic, 1989; Matelli, Camarda, Glickstein, & Rizzolatti, 1986; Petrides & Pandya, 1984), which, in turn, is reciprocally connected with the STS region (Cavada & Goldman-Rakic, 1989; Seltzer & Pandya, 1984).

Evidence of an analogous system (mirroring mechanism) in the human brain has been shown in several studies with human participants by using various techniques such as transcortical magnetic stimulation (TMS) (e.g., Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995), positron emission tomography (PET) (e.g., Parsons et al., 1995), and functional magnetic resonance imaging (fMRI) (e.g., Buccino et al., 2004; Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Iacoboni et al., 1999; Pfeifer, Iacoboni, Mazziotta, & Dapretto, 2008). In studies with EEG, activation of the motor cerebral cortex was found by mu (μ) rhythm suppression (e.g., Cochin, Barthelemy, Lejeune, Roux, & Martineau, 1998; Muthukumaraswamy, Johnson, & McNair, 2004; Oberman et al., 2005).

The MNS in humans is thought to include the superior temporal sulcus (STS), a part of the inferior parietal lobe (IPL), and the premotor cortex (PMC), including the inferior frontal gyrus (IFG) (homologous to the F5 in monkeys; Gallese et al., 1996; Gallese et al., 2004; Hari et al., 1998; Iacoboni, 2005; Keysers & Perrett, 2004; Rizzolatti et al., 1996) **(Figure 2-3**). A recent meta-analysis of 125 human fMRI studies included additional brain areas with mirror properties such as the primary visual cortex, cerebellum and parts of the limbic system (Molenberghs, Cunnington, & Mattingley, 2012). The basic premise of the MNS and mirroring mechanism in the brain is that embodied simulation can give an explanation of interpersonal relationships and its pathological disturbances (Gallese, 2009). The activation of shared neural circuits enables social identification through observation of actions, and represents a part of a system important for imitation of actions (Buccino et al., 2004; Iacoboni et al., 1999; Rizzolatti, Fogassi, & Gallese, 2002).

The MNS is often considered to be essential for the ability to engage in imitation, together with regions such as the superior temporal cortex (Carr et al., 2003). For example, although premotor and posterior parietal cortices are activated during finger movement, activation was found to be stronger when observing another person demonstrating the motion (Iacoboni et al., 1999). Similarly, transient lesions to these regions caused selective impairments of imitation (Heiser, Iacoboni, Maeda, Marcus, & Mazziotta, 2003).

Several studies have indicated that mirror activity does not reflect only simple action description, but primarily refers to intentions and meaning of actions (e.g., de Lange, Spronk, Willems, Toni, & Bekkering, 2008; Iacoboni et al., 2004). For example, Umiltà et al. (2001)

showed that mirror neurons are activated in macaque monkeys even during observation of partially hidden action, suggesting that mirror neurons code anticipation of action goals. Fogassi et al. (2005) found that parietal mirror neurons allow the observing monkey to recognise the intention of the action of the observed action, and not only its goal. Thus, it is thought that the MNS facilitates social cognitive processes, including theory of mind and empathy (Oberman & Ramachandran, 2007). Gallese (2009) rejected classical explanations of "mind reading" as internal representations of mental states of others as purely mentalistic, arguing that mirror neurons can better explain human capacity to understand others' intentional behaviour. He proposed that cognitive and neural processes that mediate ToM pertain to a process of simulation, rather than depend on explicitly attributing to others beliefs and desires (Avikainen, Forss, & Hari, 2002; Gallese, 2009; Gallese & Goldman, 1998; Gazzola, Aziz-Zadeh, & Keysers, 2006). According to the simulation theory of mindreading, others' actions are understood by "putting ourselves in their shoes". For example, a finding of stronger activation of the MNS in subjects that scored higher on a questionnaire measuring their tendency to put themselves in shoes of other people is taken as a support for the role of the MNS in empathising (Gazzola et al., 2006). Gallese (2009) describes simulation as "embodied", interpreting it as a "mandatory, prerational, nonintrospectionist process" (p. 524). According to the embodied simulation model, intentional behaviour of others is captured by "intentional attunement", or evoking behaviour, action or emotion in the observer "as if" it was doing similar action (Gallese, 2009). More studies have supported a relationship between the MNS and empathy using different tasks (e.g., Kaplan & Iacoboni, 2006; Leslie, Johnson-Frey, & Grafton, 2004).

Recently, more studies have found that mirror mechanisms are also present in sharing emotions of others (e.g., Decety & Jackson, 2004; Keysers & Gazzola, 2006; Niedenthal, 2007). For example, a functional co-dependence of the disgust experience as induced by unpleasant odours and perception of actors expressing disgust in movies was found in the transition zone between the anterior parts of the insular cortex together with the frontal opercula taste cortex (Wicker et al., 2003). Additionally, this region was also activated in another study where subjects reported experiencing more distress while viewing the distress of others (Jabbi, Swart, & Keysers, 2007), suggesting that it is involved in emotional contagion, often described as involuntary sharing of emotional states of others (Hatfield, Cacioppo, & Rapson, 1993). Studies also examined role of the MNS in empathy by using the task that included both observation and imitation of facial emotional expressions (Carr et al., 2003). This study showed that empathy is facilitated by the network consisting of the MNS,

the limbic system, and the insula connecting these two neural systems. Thus, the MNS is important for stimulating observation of facial expressions, which trigger activity in the limbic system, and the limbic system subsequently produces the emotion in the observer. Findings of this study also indicated that all regions of this network were activated during both observation and imitation of facial expressions. It was suggested, based on a simulation, that the network consisting of the MNS, the limbic system and insula subserves empathy (Goldman & Sripada, 2006; Iacoboni, 2009). An fMRI study (Pfeifer et al., 2008) examined observation and imitation of emotional expressions in typically developing children and result revealed significant activity in pars opercularis, which is considered to represent the frontal component of the MNS. This study also found correlation between activation in the MNS and children's empathy level as measured by the Interpersonal Reactivity Index (IRI) (Davis, 1983). A recent TMS study showed that MNS activity in the premotor cortex as measured during hand movement observation correlated with emotion processing from static, but not dynamic facial stimuli (Enticott, Johnston, Herring, Hoy, & Fitzgerald, 2008). This finding is taken as a support for relating the MNS to social cognition.

The anterior insula (AI) and anterior cingulate cortex (ACC) were found to be activated during viewing stimuli representing physical pain (e.g., Cheng et al., 2007; Jackson, Meltzoff, & Decety, 2005). Singer et al. (2004) found that both when subjects were experiencing pain and when viewing their loved ones receiving the same painful stimulation, the AI and ACC (together with brainstem and cerebellum) regions were activated and those regions were correlated with participants' empathy scores (Singer et al., 2004). Another study also found activation of the motor system during pain observation (e.g., Avenanti, Bueti, Galati, & Aglioti, 2005), suggesting that the observation of pain encompasses brain regions involving affective, somatosensory and motor systems (review in Bastiaansen, Thioux, & Keysers, 2009).

Figure 2-3: **The human mirror neuron system** (Illustration is adapted from Hamilton, 2013, p. 99). The image represents the core human MNS, including IFG, IPL (with aIPS). The suppression of the mu rhythm in EEG studies correlates with activation of the somatosensory cortex (BA2) while TMS studies indicate the the excitability of primary motor cortex.

primary motor
cortex (TMS)

BA2 (mu rhythm source)

anterior intraparietal sulcus
(aIPS)

Inferior frontal
gyrus (IFG / BA44)

Inferior parietal
lobule (IPL)
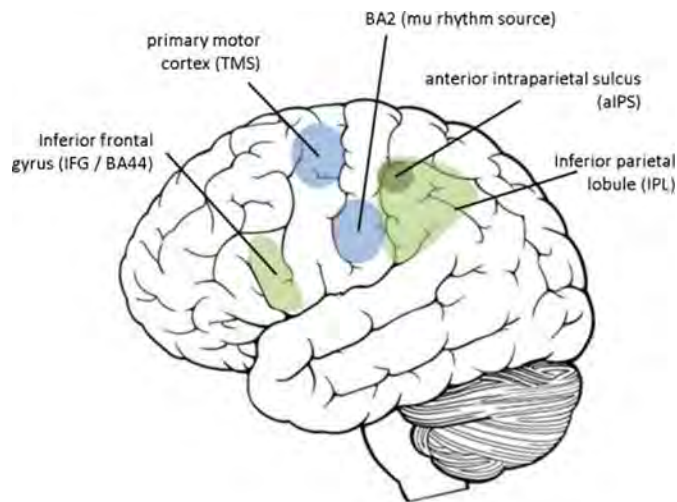
2.7.1. MNS in autism

According to Gallese et al. (2012) the theory of mind hypothesis in autism relies on reflecting consciously upon different states of mind making it similar to social meta-cognition and therefore associating it directly to linguistic competence. However, they pointed to several interdisciplinary studies that demonstrated that mentalising develops before linguistic competencies, and that understanding pointing and intention understanding are shared among different species. They suggested that motor cognition constitutes an important aspect of social cognition through its capacity to understand motor goals and intentions of others. Gallese et al. (2012) suggest that the functional development of the motor system is associated with understanding of action that is probably dysfunctional in autism. Individuals with autism lack a direct experiential understanding of the world of others that they compensate for by theorising about the others' minds. The simulation view of ToM tries to explain the deficits in mindreading in autism from several basic aspects, and one of them is anatomical and functional abnormality associated with the MNS in autism (Dapretto et al., 2006; Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2006; Williams et al., 2006). Another important aspect is based on behavioural evidence of imitation deficits in autism (Rogers & Pennington, 1991; Williams, Whiten, Suddendorf, & Perrett, 2001), as imitation is also considered to be essential for social functioning in general. The broken mirror theory (BMT) of autism is proposed as an explanation for impaired social cognition in autism. However, empirical support for this theory is quite mixed, as indicated in a detailed review of 25 papers by Hamilton (2013).

The basic impairment of imitation on which the broken mirror theory is based also has been criticised, suggesting that imitation does not depend exclusively on the MNS (Southgate & Hamilton, 2008). If it is assumed that the basic function of the MNS is not imitation itself but rather action interpretation or recognising goals of action, then it can be claimed that individuals with autism have intact MNS because they do not have dysfunctional action interpretation (e.g., Carpenter, Pennington, & Rogers, 2001; Sebanz, Knoblich, Stumpf, & Prinz, 2005). Furthermore, although a lack of imitation was considered to be a core deficit in autism (e.g., Bernier, Dawson, Webb, & Murias, 2007; Rogers, Hepburn, Stackhouse, & Wehner, 2003; Williams et al., 2006), this view has recently been questioned, with findings of normal imitation in autism (Bird, Leighton, Press, & Heyes, 2007; Press, Richardson, & Bird, 2010). An explanation for this finding is based on suggestions that children with autism do not have atypical imitation, but rather do not imitate if they are not explicitly instructed to do so (Dapretto et al., 2006; Hamilton, Brindley, & Frith, 2007). This would suggest that their main problem is in knowing when and what to imitate (Hamilton, 2008), and this ability greatly depends on recognising the social cues of others (Gergely & Csibra, 2006; cited in Southgate & Hamilton, 2008). Thus, the main problem in individuals in autism could be not imitation itself, but rather a reduced sensitivity to social cues (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Kuhl, Coffey-Corina, Padden, & Dawson, 2005).

In the following text, the review of various studies that investigated MNS function in autism is presented according to the different techniques employed. Several such detailed reviews are present in the literature (e.g., Fabbri-Destro, Gizzonio, & Avanzini, 2013; Hamilton, 2013).

2.7.1.1. EEG studies

Several studies tested the broken MNS hypothesis in patients with ASD using EEG. The suppression of the mu rhythm over the sensorimotor area is considered to be an index of mirror neuron function (Muthukumaraswamy, Johnson, & McNair, 2004). The mu rhythm is an oscillatory signal that is desynchronised during both an action observation and execution (Cochin et al., 1998). Recent studies that simultaneously recorded EEG and fMRI indicate that mu power modulation is correlated with the BOLD signal in most of the areas associated with the MNS. For example, Arnstein, Cui, Keysers, Maurits and Gazzola (2011) simultaneously recorded EEG and fMRI during action observation and execution and their results showed that suppression of the mu-rhythm as measured by EEG significantly

correlated with the BOLD signal in brain regions considered to be typically representative of the MNS: the inferior parietal lobe (IPL), dorsal premotor cortex and somatosensory cortex (BA2). However, no significant correlation was found between the mu rhythm and the BOLD signal in the BA44, which is usually considered as a source of mu-rhythm supression during action observation (Pineda, 2008).

In a detailed review of studies that examined the MNS activation in autism, Hamilton (2013) applied stringent criteria for studies that should be considered to show abnormal MNS activation in autistic group, including only studies that reported a group by condition interaction. Following this criterion, of the six EEG studies reviewed, only one study (Martineau, Cochin, Magne, & Barthelemy, 2008) showed abnormal activation of mirror neuron in children with autism, three studies showed mixed results (Oberman et al., 2005, Oberman, Ramachandran, & Pineda, 2008; Bernier, Dawson, Webb, & Murias, 2007), and two studies (Fan, Decety, Yang, Liu, & Cheng, 2010; Raymaekers, Wiersema, & Roeyers, 2009) did not find any differences in the mu rhythm suppression between individuals with autism and typical controls. In the first EEG study that examined mu rhythm suppression difference between children with autism and typically developing controls, Oberman et al. (2005) used a procedure that was later followed by several other studies. The procedure consists of four conditions: performing hand movements; watching a video of hand movements; watching a video of bouncing balls; or watching a video of white noise. Although Oberman et al. (2005) did not show a group by condition interaction, they found absent mu rhythm suppression in the autistic group during watching hand movement, but normal suppression during performing hand movement, suggesting a dysfunctional mirror neuron system in autistic subjects. In contrast, neurotypical controls showed mu wave attenuation in both conditions. In a second study, Oberman et al. (2008) found normal suppression during observation of familiar hands compared to movement of unfamiliar hands in groups of autistic male children compared to typical controls, suggesting that difference in mirror neuron activation may be the result of a lack of a social relevance of the stimuli used. This result indicates that the MNS is not completely dysfunctional in individuals with ASD, but may depend on some specific factors, such as the personal relevance of stimuli. Another study (Bernier et al., 2007) found that autistic and typical controls showed mu rhythm suppression in response to execution of actions, with groups differing in observation condition, with smaller mu wave suppression in adults with autism. The results of this study also indicated that observed smaller suppression was related to poorer imitation skills, particularly imitation of face expressions.

Raymaekers et al. (2009) used the same procedure of observing hand movements and moving hands (similar to Oberman et al., 2005) in a larger sample of autistic children and did not find any difference in mu wave suppression between the autistic and control group. This study reported significant correlation between mu wave suppression and age only in participants with autism, suggesting greater mu wave suppression is associated with older ages in the autistic group. However, Oberman et al. (2013) pooled data from four EEG studies with similar methodology and found age related changes in the mu wave suppression in both autistic and non-autistic group in response to the observation of actions task, suggesting that mu suppression is related to development, independently of autism diagnoses. Finally, the EEG study that supported abnormal mu wave suppression in autistic subjects in accordance with the criteria set by Hamilton (2013), is Martineau et al's (2008) study with children, with the task consisting of several video sequences: no stimulation; a no movement sequence; a non-human movement sequence; and a human movement sequence representing biological motion. Results showed desynchronisation of the theta 1 band (3-5.5 Hz) in healthy children during the observation of biological motion and these changes were strongest in the fronto-central areas of the left hemisphere. However, group differences were found in the posterior regions of the left hemisphere, with reduced cortical activity in these regions found in autistic children.

Recently two studies (Cooper, Simpson, Till, Simmons, & Puzzo, 2013; Puzzo, Cooper, Vetter, & Russo, 2010) examined mu wave suppression during action observation in healthy participants with high and low autistic traits as assessed by the AQ, and showed differential modulation of low beta rhythm (12-20 Hz) over motor cortex according to the level of autistic traits.

2.7.1.2. MEG studies

Magnetoencephalographic (MEG) studies have indicated spatiotemporal characteristics of oscillatory activity in different frequency ranges, and in the human brain those activities have been observed predominantly in occipital (alpha rhythm) and Rolandic (mu rhythm) areas (Hari, 1999; Tamura et al., 2005). The Rolandic area is considered to include 10-Hz (alpha) and 20-Hz (beta) oscillations (Hari & Salmelin, 1997; Pfurtscheller & Lopes da Silva, 1999). Several studies showed that the ~20-Hz rhythm originates predominantly in the precentral primary cortex and is slightly more anterior to sources of the

~10-Hz rhythm that originates predominantly in the postcentral somatosensory cortex (Salmelin & Hari, 1994; Salmelin et al., 1995).

Several MEG studies examined group differences between subjects with autism and typical controls in beta rhythm rebound, with mixed results. The beta rebound (or even-related synchronization, ERS) refers to short-lasting beta increase in synchrony after movement termination and is generally believed to reflect active deactivation (inhibition) of motor cortex networks (Jurkiewicz, Gaetz, Bostan, & Cheyne, 2006; Koelewijn, van Schie, Bekkering, Oostenveld, Jensen, 2008; Pfurtscheller, Neuper, Brunner, & Lopes da Silva, 2005; Salmelin et al., 1995). It does not necessarily depend on actual execution of movement but also can be seen after motor imagery (Pfurtscheller & Solis-Escalante, 2009). The earlier beta desynchronization (event-related desynchronization, ERD) phase represents decreases of beta band activity observed during movement is thought to originate over contralateral sensorimotor areas (Jurkiewicz et al., 2006; Pfurtscheller & Solis-Escalante, 2009). This indicates that different neural structures are activated during the earlier beta desynchronization and the following beta desynchronization/rebound (Jurkiewicz et al., 2006). Although the relationship between the beta rhythm (15-25 Hz) and the MSN are not known, the beta rhythm is considered to be similar to the mu rhythm based on its origin in the sensorimotor cortex (Salmelin & Hari, 1994). However, the beta rhythm rebound does not represent the pure index of mirror system activation. Honaga et al. (2010) showed differences between groups, with reduced post-movement beta rebound in autistic groups in response to action observation, but not in response to action execution. Reduced post-movement beta rebound in subjects with autism was found in regions associated with the MNS (the sensorimotor area, premotor cortex and superior temporal gyrus), and additionally in the medial prefrontal cortex, suggesting an impaired execution/observation matching system in autism. However, no group differences were found in autistic and typical controls in response to observed and executed actions in the Avikainen, Kulomaki and Hari (1999) study. As Avikanen et al. (1999) also found impaired theory of mind ability in autistic subjects, they suggested that mindreading impairments in autism could not be explained by dysfunctional recognition of motor actions mediated by the MNS in the motor cortex. Nishitani, Avikainen and Hari (2004) found delayed timing (longer latencies) of MEG components in the inferior frontal lobe (IF) in subjects with autism compared to healthy controls in response to imitation of lip movements. Their result suggests that impaired imitation in autism can partially be explained by dysfunctional MNS. MEG studies that examined MNS in autism are criticised

for their very small number of participant (5-8 participants), with most of them not finding strong task-by-group interaction (Hamilton, 2013).

2.7.1.3. fMRI studies

The first fMRI study that examined the MNS in autistic children found stronger activation of the right inferior frontal gyrus (IFG; pars opercularis), often interpreted as the frontal range of the human MNS, in the typical children compared to the autistic children during imitation of emotional facial expression (Dapretto et al., 2006). Results of this study also showed correlation between children's severity of autism as measured on the diagnostic test and activity in the pars opercularis, with lower activity in the pars opercularis related to more severe autism. However, some critics questioned whether those areas could be explained exclusively by the MNS (Arbib, 2007). Another criticism relates to the finding of no group differences in the amount of time spent on fixating on the face and eye regions, as measured by an eye tracker. Further criticism of this study is related to normal performance on the imitation task found in autistic children (Arbib, 2007), but Dapretto et al. (2006) explained those findings by different neural strategies between autistic and typically developing groups, similar to other suggestions of compensatory cognitive strategies used by people with autism (Rutter, 2005).

Several other fMRI studies examined the MNS in autistic compared to typically developing participants by using emotional stimuli, but without finding any significant differences between groups. For example, Grèzes et al. (2009) showed movies of neutral and fearful body movements to autistic and healthy control groups, and results did not find group differences in the mirror system for viewing neutral stimuli. Groups differences found in inferior frontal gyrus and amygdala, with reduced activation in the autistic group, were explained by different brain activation in the amygdala related to observing emotional stimuli. Bastiaansen et al. (2011) examined tasting disgusting tastes or viewing disgusting facial expressions and did not find any group differences in the MNS activation, although younger participants with autism showed lower activation in the IFG, suggesting possible age improvements in the MNS. Another study used happy and sad facial expressions in a task that required participants to decide how the person in the image feels or how the participant feels when looking at the face image (Schulte-Ruther at al., 2011). Groups did not show any differences in the inferior frontal cortex, but differed in regions generally found activated in theory of mind tasks (MPFC and the temporoparietal junction (TPJ)). Hamilton (2013) rightly

states that using emotion stimuli in those studies can be problematic because they engage brain systems associated with emotion processing, rather than the MNS itself.

Hadjikhani et al. (2007) investigated brain regions activated during the passive viewing of neutral faces, and while participants with autism did not show abnormal activation of regions typically activated during facial identity processing (FFA and inferior occipital gyrus), they showed reduced activation of the IFC and STS, areas belonging to the MNS. Results of this study also showed correlation between the severity of the social symptoms in participants with autism and cortical thinning of the right IFC.

Several other studies examined MNS activation in autism by using non-emotional stimuli. Williams et al. (2006) found decreased activation of the right parietal lobe among participants with autism during imitation of finger movements. The authors suggested that this area represents parietal MNS, and this statement was supported by not finding activation of this area during non-imitative action execution. Dinstein et al. (2010) and Marsh and Hamilton (2011) used a task with still images of hand postures and execution of hand postures, but neither of those studies found abnormal MNS activation in individuals with autism. Martineau et al. (2010) examined the observation and execution of hand movements and found group differences between high functioning autistic male participants and healthy controls in the IFG, with increased activation in participants with autism during observation of movements. The authors explained the results as representing atypical activation of the MNS in autism.

An additional explanation of MNS dysfunction in autism is found in a functional connectivity MRI (fcMRI) study that showed reduced functional connectivity between MNS regions and the primary visual cortex in individuals with ASD (Villalobos, Mizuno, Dahl, Kemmotsu, & Muller, 2005).

2.7.1.4. TMS studies

Several studies examined the MNS activation in autism by TMS. Theoret at al. (2005) applied TMS over the primary motor cortex during action execution and observation viewed from an egocentric perspective (hand was oriented as it belonged to the participants) and an allocentric perceptive (hand was oriented as it belonged to someone else) and examined activation in subjects with autism compared to healthy controls. This study found absent MEP activation (significantly lower) in adults with autism during observation of allocentric hand movement, suggesting that individuals with autism have difficulties processing other-directed

movements. Enticott et al. (2012) found absent (reduced) cortical excitability in patients with autism compared to healthy controls for tasks during the observation of hand actions (gestures). Puzzo, Cooper, Vetter, Russo and Fitzgerald (2009) investigated cortico-spinal excitability in healthy individuals with high and low autistic traits, as measured by the Autistic Quotient Spectrum (AQ), while participants viewed videos with hand and mouth actions relative to static hand and mouth actions. The results of the study revealed that participants with high autistic traits did not show different motor evoked potentials (MEPs) between moving and static stimuli, while individuals with low autistic traits showed higher MEPs during the observation of hand and mouth actions compared to static stimuli.

2.7.1.5. EMG and behavioural studies

A study showed absent EMG activity of the mylohyoideus muscle (MH) in children with autism during observation of grasping action, suggesting disrupted mirror activation in the autistic group (Cattaneo et al., 2007). A recent behavioural study (Boria et al., 2009) showed that children with autism, compared to typically developing children, showed difficulties in recognising the intention underlying an observed action (why of an observed action), with no group differences found in recognising the goal of an observed action (i. e. what of an action).

2.8. Biological motion

Perceptual sensitivity to biological motion (BM) is considered to be crucial for adaptive social interactions and social development, including the ability to recognise emotions and intentions of others (Dittrich, Troscianko, Lea, & Morgan, 1996; Frith & Frith, 1999; Kaiser, Delmolino, Tanaka, & Shiffrar, 2010a). Typically, humans show high sensitivity in recognising various movements representing biological motion, including eye movements, facial expressions and full body movements (Blake & Shiffrar, 2007). This sensitivity is considered to emerge very early in life as it is found in 2-day-old-infants (Simion, Regolin, & Bulf, 2008), although it is considered to be developed through experience and develops throughout people's lifetime (Carter & Pelphrey, 2006; Giese & Poggio, 2003; Jastorff, Kourtzi, & Giese, 2009).

Biological motion studies typically use point-light displays (PLDs) stimuli that represent human, and sometime animal, actions. Point–light displays are generated by

attaching point-lights onto key joints of an actor and filming movements (Johansson, 1973; reviewed in Blake & Shiffrar, 2007). As a result, various body actions are represented by motions of dots. A characteristic of PLDs is in isolating motion information, with limiting form motion of the display. It is possibly to extract various information from point-lights motion, including the identity of the actor (Jokisch, Daum, & Troje, 2006; Loula, Prasad, Harber, & Shiffrar, 2005), gender (Alaerts, Nackaerts, Meyns, Swinnen, & Wenderoth, 2011; Kozlowski & Cutting, 1977; Mather & Murdoch, 1994; Pollick, Kay, Heim, & Stringer, 2005), emotion (Atkinson, Dittrich, Gemmell, & Young, 2004; Chouchourelou, Matsuka, Harber, & Shiffrar, 2006; Clarke, Bradshaw, Field, Hampson, & Rose, 2005; Dittrich et al., 1996; Haberlein, Adolphs, Tranel, & Damasio, 2004; Pollick, Paterson, Bruderlin, & Sanford, 2001) or intentions (Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009).

It has been hypothesised that the brain has specialised networks for the processing of biological motion. These networks are thought to include regions traditionally considered to represent the social brain (Brothers, 1990, reviewed in Blake & Shiffrar, 2007; Giese & Poggio, 2003), in particular the superior temporal sulcus (STS) (Herrington, Nymberg, & Schultz, 2011; Jokisch, Daum, Suchan, & Troje, 2005; Kim, Park, & Blake, 2005), frontal regions (e.g., Amodio & Frith, 2006; Saygin, Wilson, Hagler, Bates, & Sereno, 2004) and limbic regions (e.g., Bonda, Petrides, Ostry, & Evans, 1996). Particularly important for biological motion processing is the STS, as indicated in studies with lesion patients and TMS (e.g., Grossman, Battelli, & Pascual-Leone, 2005; Saygin, 2007). Various fMRI studies also showed activation of the posterior superior sulcus (pSTS) in response to biological motion (Pelphrey et al., 2003; Puce et al., 1998), including responding to intentional movements (e.g., Castelli, Happé, Frith, & Frith, 2000; Pelphrey, Morris, & McCarthy, 2005a; Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005b).

Some other regions implicated in BM include the extrastriate body area (EBA), also activated in response to static images of the human body (e.g., Downing, Jiang, Shuman, & Kanwisher, 2001; Taylor, Wiggett, & Downing, 2007). Another region activated in response to BM stimuli is the homolog of the middle temporal gyrus in monkeys (hMT/V5) and the kinetic occipital (KO) region, typically involved in general motion processing (e.g., Peuskens, Vanrie, Verfaillie, & Orban, 2005; Santi, Servos, Vatikiotis-Bateson, Kuratate, & Munhall, 2003; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001; but not found in Grossman & Blake, 2002; Downing et al., 2001).

Several MEG studies investigated oscillatory responses to BM stimuli. For example, Pavlova, Lutzenberger, Sokolov and Birbaumer (2004) found increased oscillatory responses

between 25 and 30 Hz over the left occipital cortex as early as 100 ms in response to both upright and inverted PLDs, and activation over parietal and right temporal cortices in later frequencies. This activation was absent for scrambled PLDs. Pavlova, Birbaumer and Sokolov (2006) found gamma responses as early as 80 ms over the left parieto-occipital cortex. In another MEG study, Virji-Babul, Cheung, Weeks, Kerns and Shiffrar (2007) found increased oscillatory response between 15 and 35 Hz over the left posterior temporal area between 250 and 350 ms in response to PLDs representing human motion, but not for non-human motion.

Biological motion processing has been investigated with several studies generally comparing ERPs of canonical PLDs to scrambled PLDs. Findings revealed activities that BM stimuli enhanced two components: an earlier component peaking around 170-200 ms post-stimulus onset, and a second component peaking around 200–300 ms (Hirai, Fukushima, & Hiraki, 2003; Hirai & Hiraki, 2006; Hirai, Senju, Fukushima, & Hiraki, 2005; Jokisch et al., 2005; Krakowski et al., 2011). Both of those components were typically found maximally over posterior occipito-temporal scalp regions. A recent study proposed that the later component that peaks around 200 ms (labelled the N200) represents an index of form and motion integration, rather than biological motion processing per se (White, Fawcett, & Newman, 2014). Furthermore, a high-density electrical mapping study (Krakowski et al., 2011) indicated that differential activation of biological and scrambled motion occurs already by about 100 ms latency, with continuous significance occurring 320 ms onward over occipital scalp regions, dependent on explicit attention to differentiate biological and scrambled motion.

Saygin et al. (2004) in their fMRI study were the first to find a clear response to point-light biological motion animations in the premotor brain regions containing mirror neurons. This study showed activation of the frontal cortex in response to biological motion stimuli only, but not when the same stimuli were scrambled. Several studies observed significant suppression of the alpha range of electrophysiological mu rhythms (8-13 Hz) in response to PLDs, which authors associated with mirror neuron activity in premotor cortex (e.g., Perry, Troje, & Bentin, 2010; Ulloa & Pineda, 2007).

2.8.1. Biological motion in autism

Biological motion recognition has been found to be disrupted in subjects with autism (a detailed review of evidence for impaired biological motion deficit in autism is given by

Kaiser and Pelphrey, 2012). In an eye tracking study (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009), 2 year old children with autism were found to differ from typically developing children in viewing patterns that focused on non-social objects, with impaired perceptual sensitivity towards socially salient point-light displays of canonical biological motion, and preferential attending to non-social aspects of biological motion. Previous neuropsychological studies on (impaired) BM detection in children and adults with autism are inconclusive. Several behavioural studies have found impaired biological motion processing in autism (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Kaiser et al., 2010b). Some studies, although not finding any difference in the recognition of BM between autistic and healthy subjects on the visual processing of simple actions, found that autistic subjects have problems in the interpretation of the internal states of others (Moore, Hobson, & Lee, 1997), that is, impaired recognition of emotional point-light displays (Hubert et al., 2007; Parron et al., 2008). Several recent studies found normal biological motion processing in adults with autism (Murphy, Brady, Fitzgerald, & Troje, 2009; Saygin, Cook, & Blakemore, 2010). These studies indicate better performance on biological motion tasks in adults compared to children, suggesting possible developmental improvements for autistic subjects on biological motion tasks.

In order to find out whether impaired biological motion processing in autism is due to biological motion processing per se or disrupted global motion processing, Kaiser et al. (2010a) investigated visual processing of human, animal and object motion, with results showing equivalent processing of all three types of motion in individuals with autism, while typically developing individuals showed increased sensitivity to only human and animal motions. Similarly, Koldewyn, Whitney and Rivera (2010) found impaired biological motion and coherent motion in adolescents with autism compared to typically developing subjects, but only impaired biological motion processing was found when IQ results were accounted for.

Recent fMRI studies that compared processing of biological and scrambled motions in autistic and control subjects showed hypoactivation of posterior superior temporal regions in autistic groups (Freitag et al., 2008; Herrington et al., 2007). To date, only one study has investigated temporal processing of biological motion, comparing children and adolescents with autism to typically developing controls (Kröger et al., 2013). Results of this study indicate deficits in the autistic group, starting at short latencies at the P100 component (i.e. around 100 ms), suggesting early visual perceptual deficits not limited to biological motion. Reduced activity after 400 ms was interpreted as an indicator of disrupted brain activation for biological motion processing. More studies are needed to give definite answers about

atypicalities of biological motion processing in autism, and those answers can help in better understanding social dysfunction in autism.

2.9. Summary

Although there is a general evidence of abnormal face and facial emotion processing in individuals with autism, with atypical functioning found in main regions of the social brain, including the amygdala, STS and FFA, further clarification is needed. Findings in autism suggest the importance of visual processing research in autism, and possible future connections to be found between visual processing and social and emotional processing in this group. The importance of visual research in autism is supported by evidence of significantly more visual problems in individuals with autism than individuals without autism (Milne & Griffiths, 2007). Some evidence is also found for an altered subcortical pathway for processing of social stimuli in individuals with autism (Fujita et al., 2013). The current status of the neural basis of social cognition in autism also suggests the need for further investigation of the interrelationship between various regions in autism. Schultz et al. (2000) suggested a link between amygdala dysfunction in autism and the fusiform gyrus, proposing that an early lack of interest in faces and other socially salient information is a cause of an early disruption in the amygdala and its connections to temporal cortices, including the FG. The interaction of cognitive-perceptual and socially salient information in various facial expressions could depend on better explanation of connections within social brain network in autism, including the subcortical route of this network.

Furthermore, dysfunction of the MNS in autism can be found, this dysfunction in autism is not fully accepted because of evidence of robust MNS function in the disorder (Dinstein et al., 2010; Marsh & Hamilton, 2011). It is also not easy to give a conclusive explanation of the various findings. For example, Southgate and Hamilton (2008) suggested that findings of impaired MNS in autism based on the reduced mu rhythm suppression over sensorimotor cortex could not be explained only by atypical MNS in autism compared to control participants (e.g., Oberman et al., 2005), but also to atypicalities in earlier visual processing. The examples they cite include findings of decreased attention to social stimuli (Klin et al., 2002), difficulties in processing of biological motion (Blake, Turner, Smoski, Pozdol, & Stone, 2003) and in understanding of complex visual information (Behrmann, Thomas, & Humprheys, 2006) in autism as potential sources of dysfunctional the MNS in autism. The importance of the MNS investigations for autism lies in its possible role in

clarifying motor deficits in social and communicative impairments found in autism. It is suggested that motor difficulties in autism may be essential for cognitive-communicative deficits in autism (Fabbri-Destro et al., 2013). More research is required to better understand the role of the MNS in autism and if it is impaired in the autism disorder.

Finally, evidence of atypical processing of biological motion in autism suggests a low level visual difficulty (including motion processing) in this disorder. Other important findings are difficulties in extracting emotions from PLD stimuli in subjects with autism compared to typically developing subjects, which can be also seen in differential activation of brain circuits for those stimuli that are not related to low-level motion areas (Simmons et al., 2009). Simmons et al. (2009) suggested that it may be possible that biological motion stimuli are less salient for individuals with autism because of differences of threshold recognition in this group, and therefore any study that would transform stimuli in order to equate performance between groups could try to see what difference this would produce on the neural activation.

CHAPTER 3 –

THE BROADER AUTISM PHENOTYPE (BAP)

3.1. Heritability of autism

There are three major study designs that have examined the genetic origin of autism: twin studies, family studies, and investigation of syndromes and chromosomal disorders strongly related to autism (review in Geschwind, 2013). Autism is considered to be a strongly heritable disorder, although research has not yet agreed on specific genetic linkages to autism (Muhle, Trentacoste, & Rapin, 2004). However, it is considered that multiple genetic factors may contribute to the phenotype (Geshwind, 2013; Muhle et al., 2004), and previous studies of multiplex-families with the broader autism phenotype (families with two or more affected children), as well as studies of twins, suggest that single-gene deficits are rarely found even within families (Muhle et al., 2004). Besides "complex genetics" (suggesting that susceptibility to autism is a result of different groups of genes acting together), other factors important in autism are "variable penetrance", meaning that the autism phenotype is not displayed by all carriers of a particular risk allele, and "variable expressivity", meaning that there are different ways that a phenotype is expressed (Geschwind, 2013, p. 84; Veenstra-Vanderweele, Christian, & Cook, 2004).

Studies that have investigated the heritability of autism provide evidence for both concordance and recurrence of autism in siblings (Sasson, Lam, Parlier, Daniels, & Piven, 2013). A recent longitudinal prospective study (Ozonoff et al., 2011) reported that 18.7% of infants with older siblings with autism developed the disorder, with an increased risk of developing autism for males and in families with more than one older sibling with autism. The recurrence rates in this study were higher than in older studies that reported a recurrence risk ranging from 3% to 14% (in Ozonoff et al., 2011). Constantino et al., (2010) found that recurrence rates occur in 10% of families with an older autistic sibling using the traditional definition of ASD, but reported an additional 20% of unaffected siblings experiencing language delays. The study also reported a large presence of sub-clinical autistic traits among children with no autism in multiple-incidence families but not in single-incidence families. Szatmari et al. (2000) compared biological and nonbiological relatives (adoptive families) of children with pervasive developmental disorder (PDD) and showed that PDD-like traits or milder manifestations of the disorder were found in biological relatives, particularly within multiplex families (families with two affected PDD children) compared to simplex families (families with one PDD child), and also when the child with autism had high functioning autism or an IQ above 60.

Twin studies have provided important evidence for genetic factors causing autism, with older studies, which were based on a narrower definition of autism, showing concordance rates between 60-96% in monozygotic (MZ) twins and 0–23% in dizygotic (DZ) twins (e.g., Bailey et al., 1995; Ritvo, Freeman, & Mason-Brothers, 1985; Steffenburg et al., 1989). When using a broader autism phenotype (BAP), the MZ concordance rate was 92% and the DZ concordance rate was 10% (Bailey et al., 1995). Several recent twin studies that applied new criteria for ASD diagnosis found concordance rates between 50-95% in MZ and 4-36% in DZ twins (Hallmayer et al., 2011; Lichtenstein, Carlström, Råstam, Gillberg, & Ankarsäter, 2010; Nordenbæk, Jørgensen, Kyvik, & Bilenberg, 2013; Rosenberg et al., 2009; Taniai, Nishiyama, Miyachi, Imaeda, & Sumi, 2008). In sum, the original twin studies of autistic disorder and the new studies of autism have all indicated high heritability for this disorder.

Several twin studies assessed heritability of autistic traits in the general population by using various quantitative scales. Results indicated that heritability estimates range from 36% to 87% in twin samples aged between 2 and 18. For middle childhood and older groups, heritability estimates were higher for parent- and teacher-rated autistic traits (between 60% and 90%), compared to self-reported assessments of autistic traits (between 36% and 57%) (Hoekstra, Bartels, Verweij, & Boomsma, 2007; Ronald, Happé, & Plomin, 2008). Twin studies with 2 year old children found moderate heritability (40% and 44%) of parent-rated autistic traits (Edelson & Saudino, 2009; Stilp, Gernsbacher, Schweigert, Arneson, & Goldsmith, 2010), suggesting a possible increase of heritability of autistic traits with age. However, similarity in heritability estimates for autism and autistic traits cannot prove that the same genetic factors are involved (Ronald, Happé, Price, Baron-Cohen, & Plomin, 2006b; Ronald & Hoekstra, 2011). A detailed comparison of twin studies that were conducted before 2010 was conducted by Ronald and Hoekstra (2011). The authors highlighted the usefulness of twin studies for recognising environmental influences on autism, although even when environmental risks are identified, it is difficult to determine their independence from genetic effects because an individual's genotype may modulate exposure to environmental effects. They consider that gene–environment interaction is present when there is a mutual interaction between the genotype of an individual and the effect of an environment on the outcome, such as when the environment that the person is exposed depends on an individual's genotype. The authors suggest that in shared environments, its effects will be underestimated, as the individual's genes and environment will mimic genetic effects, whereas in non-shared

environment, genetic effects will be underestimated. Furthermore, although the non-shared environment has a small influence on autism and autistic traits, this influence can be potentially important. The authors also emphasised the importance of twin studies for describing autism as a continuously distributed trait.

Some studies have used structural MRI to examine neuroanatomical differences between twins who are discordant for narrow autism. For example, strong concordance across pairs was found in cerebral grey and white volumes and also in reduced frontal, temporal, and occipital white matter volumes (Kates et al., 2004). When examining specific brain regions including prefrontal cortex, amygdala and hippocampus, within-pair neuroanatomical concordance varied within the brain region (Mitchell et al., 2009).

Family studies show that when autism is present in a family, the risk that the next sibling is diagnosed with autism is about 10% (Geschwind, 2013). Depending on how the population risk/population prevalence of autism is estimated, it is estimated that siblings of individuals with autism have a 20- to 50-fold increase of being autistic in comparison to the general population (in Geschwind, 2013; Abrahams & Geschwind, 2008; Gupta & State, 2007; Veenstra-Vanderweele, Christian, & Cook, 2004). Geshwind (2013) states that although both twin and family studies clearly show that younger siblings of individuals with autism are at higher risk of developing autism, they cannot give a full explanation as to the mode of inheritance.

Examinations of syndromes and chromosomal disorders have revealed that between 10% and 15% of people with autism have identifiable genetic impairments (Abrahams & Geschwind, 2008; O'Roak & State, 2008). For example, Fragile X is present in about 1% to 2% of individuals with autism, and 25% of patients with Fragile X have an ASD (Bailey et al., 1993; Brown et al., 1986). Also, maternal inherited duplication of chromosome 15q11-13 accounts for 1% to 2% of autism (Cook et al., 1997). Some genetic syndromes, such as Timothy syndrome (a very rare heart abnormality) (Abrams & Geschwind, 2008), Turner syndrome (a disorder found mostly in females in which all or part of one X chromosome is deleted) (Skuse et al., 1997; Skuse, Mandy, & Scourfield, 2005), and Smith–Lemli–Optiz syndrome (a mental retardation syndrome) (Tierney et al., 2001), have high proportion of autism or autistic features (review in Abrahams & Geschwind, 2008). In addition, Rett syndrome, a progressive neurodevelopmental disorder that is the most common in females, was originally misdiagnosed as autism because it also involves social impairment, and

individuals with Rett syndrome mostly have autism (Amir et al., 1999). A single gene mutation of the MECP2 gene was suggested to be a cause of many cases of Rett syndrome, however studies that examined the MECP2 mutation in autism have provided conflicting results, with some suggesting that mutations in the MECP2 did not have an important role in autism susceptibility (Beyer et al., 2002; Vourc'h et al., 2001), another study showed that 2 out of 69 cases of autism involved mutation in the MECP2 (Carney et al., 2003). However, although the MECP2 mutation may not have an important role in autism, Zoghbi (2003) has proposed that a cause of both autism and Rett syndrome could be the disruption of synaptic plasticity.

3.2. Endophenotypes in autism

There has been increasing interest in the possibility of describing specific heritable cognitive-behavioural components, or endophenotypes, which are not part of the diagnostic symptoms of autism (Rutter, 2005a, 2005b). It is suggested that those endophenotypes may be less heterogeneous than the autistic syndrome (Rutter, 2005b), thus representing more stable traits, and that relating those specific domains of autism to genetic risk may be simpler than investigating the entire autism syndrome at once (Geshwind, 2013). In autism research, some endophenotypes include language ability (Losh et al., 2012), social behaviour (Duvall et al., 2007), nonverbal communication (Chen, Kono, Geschwind, & Cantor, 2006), repetitive and restrictive behaviours (Moruzzi, Ogliari, Ronald, Happé, & Battaglia, 2011), increased head circumference (Chaste et al., 2013; Constantino et al., 2010), biochemical factors including gene expression (Nishimura et al., 2007), and even facial asymmetry (Hammond et al., 2008). In general, it is thought that to be considered as a criterion for an endophenotype, "a marker must be present in affected individuals, has to be heritable and co-segregate with the illness, it should be state-independent (i.e., manifests in an individual whether or not the illness is active), and must be found among unaffected relatives of patients at a higher rate than in the general population" (Delorme et al., 2007, p. 32-33).

3.3. Describing the Broader Autism Phenotype (BAP)

A subset of relatives of individuals with autism show mild versions of part of the autism phenotype, for example, social and language deficits and restricted interests and behaviour (Landa et al., 1992; Landa, Folstein, & Isaacs, 1991). These subclinical impairments in social skills, communication abilities and personality traits are exhibited at a higher rate in relatives of individuals with autism compared to the general population, and are

generally considered to characterise the Broader Autism Phenotype (BAP) (Gerdts & Bernier, 2011; Piven et al., 1997c; Piven & Palmer, 1997a, 1999; Piven, Palmer, Jacobi, Childress, & Arndt, 1997b). Studies have usually compared parents of individuals with autism with parents of a clinical control group, such as parents of children with Down syndrome (e.g. Di Michele, Mazza, Cerbo, Roncone, & Casacchia, 2007) and Prader-Willi syndrome (Szatmari et al., 2008). The aim of such comparisons is to eliminate the possibility that the effect may be influenced by a stressful family environment due to caring for a child with a disability (Di Michele et al., 2007; Sucksmith, Roth & Hoekstra, 2011). Other studies compared parents (e.g., Losh et al., 2009) and siblings (e.g., Shaked, Gamliel, & Yirmiya, 2006) of autistic individuals with individuals that have no family history of developmental disorders. Studies also compared siblings of individuals with autism who are unaffected with the disorder, although some studies included affective relatives (e.g. Virkud, Todd, Abbacchi, Zhang, & Constantino, 2009), making comparison difficult because of the impact of autistic traits on this comparison. Currently it is popular to investigate early markers of the BAP in infancy (e.g. Elsabbagh et al., 2009), but as Sucksmith et al., (2011) explained, they are not clearly representing the BAP, as many of them are "at-risk" of developing autism. Because an autism diagnosis cannot be given to this group, they will be mostly omitted in the present review of the BAP. Thus, the main approach should consider that the BAP represents only those individuals who are not affected by the disorder and consequently do not have a diagnoses of autism. Another approach for analysing the BAP is by examining autistic traits in the general population by using various instruments. Ideally, analysis of the BAP in the general population should also exclude those individuals that have first-degree relatives with autism.

There are methodological differences among many of the studies that have examined the BAP, besides the differences related to the selection of participants mentioned above. For example, early studies examining autism-related characteristics in the relatives of individuals with autism were predominantly behavioural and often used interviews, observational assessments, self/other-report questionnaires, and life-history methodology (e.g., Piven et al., 1997b, 1997c; Szatmari et al., 2000). However, the BAP can also be examined from the cognitive level, by investigating social cognition, executive function and visual attention. Neuroimaging studies have also been used to examine possible neuroanatomical and neurofunctional correlates of the BAP. Sucksmith et al., (2011) gives a detailed review of all studies on the BAP that were based on behavioural, cognitive and neuroimaging characteristics. Examination of the broad autism phenotype has become possible only after

the publication of standardised diagnostic instruments in the early 1990s that ensured the diagnosis of autistic individuals was similar across sites and countries (Yirmiya & Ozonoff, 2007). As a result, the first sibling study was initiated, with data collected from the U.S., UK and Sweden (Yirmiya et al., 2006; Yirmiya, Gamliel, Shaked, & Sigman, 2007).

Dawson et al., (2002b) proposed six candidate BAP traits for genetic studies to focus on: (a) face processing, including structural encoding of facial features and eye gaze; (b) social reward sensitivity; (c) motor imitation ability; (d) memory; (e) executive function; and (f) language ability (p. 581). It is interesting to note that, although the weak central coherence theory is one cognitive theory of autism, and locally oriented visual processing in autism is identified in many studies, it was not included in the candidate BAP traits. Perceptual deficits in autism, although having been reported in autism for diverse perceptual tasks (e.g., Bertone, Mottron, Jelenic, & Faubert, 2003; Dakin & Frith, 2006; Pellicano et al., 2005), are not included in diagnostic criteria. Although encoding of facial features also partially includes focus on featural or local processing of visual information, this explanation would only focus on facial stimuli, excluding non-face stimuli. An increasing number of studies have been investigating many of those BAP traits, not only among relatives of individuals with autism, but also by looking at neurotypical individuals with higher autistic traits. Furthermore, there has been a constant effort to develop suitable instruments for describing autistic traits in both autistic relatives and in the general population. Some of these instruments will be described in following chapters.

3.4. The BAP tests

There are a variety of methods and questionnaires that have been used to assess autistic traits in a quantitative way (e.g., Baron-Cohen et al., 2001; Constantino, 2002; Constantino & Todd, 2005; Ronald et al., 2006s). These studies suggest that autism lies on a continuum from almost no autistic traits to high scores in the autistic disorder. This theory suggests that unaffected family members of a person with autism should show higher scores on quantitative measures of autistic traits compared to general control groups, and higher scores should be found in multiple incidence compared to single incidence families (Virkud et al., 2009). De la Marche et al. (2012), however, did not find higher scores in multiple incidence families.

Recently, additional methods have been developed for assessing the BAP. For example, the Social and Communication Disorders Checklist (SCDC) is a simple 12-item

questionnaire for measuring autistic traits in children without a learning disability, and was found to be appropriate for large-scale population screening (Skuse, Mandy, & Scourfield, 2005). The Autism Family History Interview (AFHI) (Bolton et al., 1994) was used to assess the BAP in first- and second- degree relatives of autistic people and controls by using informant design. The Broad Autism Phenotype Symptom Scale (BAPSS) (Sung et al., 2005) was also constructed and showed heritability of parts of the BAP by using family history and direct assessment approaches. The Modified Personality Assessment Schedule-Revised (MPAS-R) (Piven et al., 1994), a semi-structured interview protocol for rating personality characteristics, was used for assessing parents of autistic individuals and individuals with Down's syndrome. Characteristics that can be rated through this measure include aloof and rigid personalities, which were found in greater measure in parents from multiple-incidence families (parents with more than one child with autism), and is considered to be an important component of the BAP (Piven et al., 1997). The Broad Autism Phenotype Questionnaire (BAPQ) is a scale partially based on the MPAS-R, created for assessing aloofness, rigid personality and pragmatic language problems (Hurley, Losh, Parlier, Reznick, & Piven, 2007). It has been demonstrated that parents of children with autism score significantly higher on all three subscales of the BAPQ compared with parents of typically developing children (Hurley et al., 2007). Aloof personality is described as a personality marked by a lack of interest in social interaction, and rigid personality as a personality marked by difficulty adjusting to change.

Two questionnaires, The Social Responsiveness Scale (SRS, Constantino, 2002) and the Autism-Spectrum Quotient (AQ, Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) were developed to measure autistic traits, but have been also used to measure the BAP. The SRS (Constantino & Gruber, 2005; Constantino, 2002) is a 65-item questionnaire that assesses primarily reciprocal social behaviour, although it also includes items that assess communication and the repetitive/stereotypic behavioural characteristic of autism. Items are scored by using informant design, that is, a design where the behaviour under study is scored by parents or caregivers, with higher scores indicating more autistic traits. High SRS scores were found in siblings of autistic children (Constantino et al., 2006).

Baron-Cohen, Wheelwright, Skinner, Martin, and Clubley (2001) constructed the Autism-Spectrum Quotient (AQ) to test the assumption that autism conditions lie on a continuum of social-communication skills. The AQ is a self-administered questionnaire that

consists of 50 items, comprising five sub-scales: social skill, attention switching, attention to detail, communication, and imagination.

The review of the BAP in this chapter will be divided into findings related firstly to the main cognitive theories of autism, and later to social and emotional functioning, regardless of the methodology used in studies. The review will predominantly focus on studies with unaffected first-degree relatives of individuals with autism, and also on investigations of autistic traits in the general population that examined non-social and social aspects of the BAP separately. The rationale for investigating the BAP across various domains found to be impaired in autism (i.e., social functioning, language and communication difficulties, and repetitive and restricted interests and behaviours, including psychological theories of autism) lie in the suggestion that there are not specific mild, non-pathological autistic traits that can define the BAP, and even more that it is not clear which traits can precisely represent the BAP (Scheeren & Stauder, 2008). There are more studies suggesting that although impairments were found across all those domains that were found to be impaired in autism, they may segregate independently in unaffected relatives of people with autism (e.g. Bailey et al., 1998; Bolton et al., 1994; Piven et al., 1997), which suggests that specific impairments found in autism might be inherited separately (Pellicano, 2011). Although only a few studies have examined the correlations between the BAP traits, Mundy and Skuse (2008) reviewed several large BAP studies (e.g., MFHS, Bolton et al., 1994; JHS, Piven et al., 1997) that reported a larger proportion of relatives with communication and social impairments than with non-social impairments, and in general, their findings suggest that only a very small number of relatives of autistic children had impairments in all three domains. The review of BAP studies also suggests that only isolated autistic traits appear in relatives of individuals with autism, rather than a mild form of the disorder that would include all domains (Mundy & Skuse, 2008). Furthermore, findings from a population-based study investigating autism-related social, communicative and repetitive traits in typically developing twins in children groups found modest-to-low cross-trait genetic correlations both across the general population and in children with extreme autistic traits, suggesting independent genes for each aspect of the triad of impairments in autism (Ronald et al., 2006a). In addition, various psychological theories of autism, specifically social cognition, executive functions and weak central coherence, were also found to be present in different degrees in healthy participants with the BAP. Recently, Losh et al., (2009) demonstrated that the social cognitive domain, as investigated by tasks that had been designed to reflect

amygdala function, significantly differed between individuals with autism and parents with the BAP from control groups. This study did not find group differences in measures of executive functions and central coherence, suggesting the importance of social cognitive measures for explaining the heredity of autism. In this study, characteristics of the BAP were measured by clinically based interviews using the Modified Personality Assessment Schedule-Revised, or MPAS-R. Recently, a study examined the BAP in 5-years old siblings of children with autism, and showed vulnerabilities in this group on measures of executive functioning, social cognition, and repetitive behaviours (Waren et al., 2012). In sum, these findings show the importance of investigating various domains in the BAP that are found impaired in autism to find those that co-exist within the BAP and in what measure.

3.5. BAP and cognitive theories of autism

Recently, there has been increased interest in examining the cognitive characteristics of the broad autism phenotype (reviews of earlier studies can be found in Bölte & Poustka, 2006).

3.5.1. Executive functions in the BAP

Concerning executive dysfunction deficits, patterns found in parents and siblings of individuals with autism indicate similarities with autism, which suggests that executive function deficits could have underlying genetic causes and may be a part of the BAP. Earlier studies showed evidence for executive function difficulties in relatives of people with autism, particularly reduced planning abilities, as examined in the Tower of Hanoi and Tower of London tests (Delorme et al., 2007; Ozonoff, Rogers, Farnham, & Pennington, 1993; Piven, & Palmer, 1997; Hughes, Leboyer, & Bouvard, 1997a; Hughes, Leboyer, & Plumet, 1999; Hughes, Plumet, & Leboyer, 1999), however findings were inconclusive or negative on other measures of executive functions (Szatmari et al., 1993; Ozonoff et al., 1993). Although studies on working memory in first-degree relatives of individuals with autism are not numerous, several studies showed working memory difficulties in this group (Delorme et al., 2007; Hughes et al., 1997a, 1999).

In contrast to earlier studies, Wong et al. (2006) did not find difficulties in parents and siblings of autistic individuals related to planning (by using the Tower task), inhibition ability tasks, or the interaction between inhibition and working memory, and set-shifting impairment was found only in fathers of autistic individuals. However, this study showed that important

differences in generativity (ideational fluency, described as generating more than one strategy to solve a problem) were found between parents and siblings of autistic individuals and control groups of parents and siblings of individuals with mild intellectual disabilities. Wong et al., (2006) suggested that the executive function deficits found in the BAP may be primarily characterised by strength and weakness in various executive function measures, but that impairments in generativity may have an essential role in cognitive theories of autism.

3.5.2. Weak central coherence in the BAP

Support for local processing bias was also found in first-degree relatives of individuals with autism. In an early study that investigated cognitive theories of autism in parents and siblings, Happé, Briskman, and Frith (2001) compared the performance on four central coherence tasks (the Block Design, the Embedded Figures Test, Visual illusions, the Sentence Completion task) between parents and siblings of individuals with autism with parents and siblings of individuals with dyslexia and no developmental disorders. Results revealed that fathers of individuals with autism differed from other groups by showing better performance on all the central coherence tasks that required piecemeal processing. Mothers of individuals with autism did not differ from controls on central coherence tasks, suggesting gender differences in central coherence among ASD relatives. This study also used a self-ratings and parental ratings of children protocol to assess everyday social and non-social preferences in siblings of children with autism (Briskman, Happé, & Frith, 2001). Items of the survey were based on the weak central coherence account (non-social items) and on the theory of mind account of autism (social items). Results failed to find any differences between siblings of individuals with autism and control group, and were explained by underestimated ratings of autistic siblings by their parents because of an implicit comparison with a much more affected autistic child. Those results are consistent with other studies that did not find differences in siblings of children with autism even with a larger sample (e.g. Folstein et al., 1999; Yirmiya, Shaked, & Erel, 2001). However, the self-ratings of parents with autistic children indicated a preference for solitary activities and had less interest in social interaction. They differed from parents of dyslexic children and control group parents on the non-social questions, and showed weaker central coherence as indicated by their preference for detailed-focused interests, memory of factual information, and sensitivity to slight changes. Fathers of children with autism obtained noticeably higher scores on non-social items (Briskman, Happé, & Frith, 2001). An investigation into potential correlations between items showed a correlation between social and non-social items in autistic fathers, with higher scores indicating the lack

of social interests in conjunction with more detailed interests. Other studies provide evidence of specific visual processing in fathers of children with autism. For example, Scheeran and Stauder (2008) showed that autistic fathers, when compared to control fathers, perform better on the Block Design Test, but this difference was not found for autistic mothers compared to control mothers. Interestingly, strong evidence of the BAP in fathers was also found in an earlier study that showed worse performance on a spatial memory task in fathers of children with autism compared to fathers of typically developing children, with no differences found between the groups of mothers (Hughes et al., 1997a).

Several other studies did not find differences between parents of children with autism and control groups on the Block Design Test (Fombonne, Bolton, Prior, Jordan, & Rutter, 1997; Piven & Palmer, 1997; Scheeren & Stauder, 2008), suggesting that the Block Design Test is not sensitive enough for measuring subtle differences in local information processing (Scheeren & Stauder, 2008). However, parents of children with autism showed a tendency for local processing as assessed by the Embedded Figure Test (EFT) (Baron-Cohen & Hammer, 1997; Bölte & Poustka, 2006).

Visual processing characterised by enhanced local processing or reduced processing of global information as observed in autism is investigated in several studies by dividing subjects in groups with low and higher autistic tendency, as measured by the Autism Spectrum Quotient (AQ). For example, Grinter, Beek, Maybery, and Badcock (2009a) found better performance (faster and fewer errors) of individuals with high AQ compared to those with low AQ on the EFT and the Block Design test. Results on the EFT differed from a previous study with a Japanese sample divided in low and high autistic tendency that did not find a better performance on the EFT in higher AQ scorers (Kunihira et al., 2006). It was suggested that the Japanese sample included participants with higher AQ means, leading to higher cut-offs for the low AQ group than those used in the Grinter et al., (2009a) study. The study by Grinter et al., (2009b) supported findings of better performance for subjects with high AQ on the EFT. This study also showed poorer global motion and global form thresholds in people with high AQ compared to those with low AQ as examined by the Global dot motion and a Glass pattern stimuli. Glass pattern stimuli have been reported to activate V4 of the ventral visual stream (Wilkinson et al., 2000; Wilson & Wilkinson, 1998) suggesting poorer "global grouping capability within the ventral cortical pathway" (Grinter et al., 2009b, p. 1286) in subjects with high AQ. Impaired performance on the Global dot motion task in subjects with high AQ is consistent with previous findings of reduced

sensitivity to these stimuli in people with autism (Pellicano et al., 2005; Spencer et al., 2000), although several studies did not find any difficulties in processing these stimuli in individuals with autism (Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006; White et al., 2006). Grinter et al. (2009b) suggest that their result indicates that people with high AQ have difficulties with higher-level integrative processing in the dorsal motion pathway. Grinter et al. (2009b) did not find differences between high and low AQ groups on the pulsed-pedestal task that measures low-level visual processing in the parvocellular stream, suggesting that findings of impaired Glass pattern and the Global dot motion task in subjects with high AQ may be a consequence of less efficient mechanisms for combining local form signals into a global form percept. Therefore, visual processing in both individuals with high autistic traits and individuals with autism deserves more investigation, as previous findings are inconsistent. So far, Bertone, Mottron, Jelenic, and Faubert (2003) have proposed that individuals with autism do not have a visual motion processing abnormality indicative of dorsal stream functioning, but show difficulties in second-order motion processing that requires integration of complex perceptual information. A further more detailed investigation into perceptual processing in the broad autism phenotype is certainly needed, preferably featuring first-degree relatives of individuals with autism.

A processing bias for local visual information in autism is considered to be responsible for this group to be less susceptible to many visuospatial illusions, because they possess less ability or inclination to integrate various elements that leads to the illusions (Walter, Dassonville, & Bochsler, 2009). Less susceptibility to illusions for subjects with autism was found by Happé (1996), although several later studies found that individuals with autism do not differ from individuals without autism in susceptibility to illusions (Hoy, Hatton, & Hare, 2004; Ropar & Mitchell, 1999; 2001). Walter et al., (2009) investigated susceptibility to eight visual illusions (e.g., rod-and-frame illusion, etc.) in subjects with high and low autistic traits (AQ). Results showed correlation of a subset of visual illusions with the Systemizing Quotient (SQ). The "systemising" describes a drive or tendency to construct and analyse systems, and is suggested to reflect an attention to detail, and therefore is related to the WCC (Frith, 1989; Happé & Frith, 2006) and EPF (Mottron et al., 2006) theories. Walter et al., (2009) did not find correlation between susceptibility to visual illusions and the AQ scale or any of its subscales, particularly the "attention to detail" subscale, although the "attention to detail" and "imagination" subscales significantly correlated with the SQ. This result is explained by fewer questions found in the AQ subscale, and more questions assessing

systemising can be found in the SQ questionnaire. In summary, results of this study show that the high systemising traits show susceptibility to a subset of visual illusions, suggesting that there is a bias to local visual features in the typically developing individual with higher systemising autistic traits.

Another study used an interesting design in order to investigate the EFT performance of specific subgroups of participants with different autistic traits (Russell-Smith, Maybery, Bayliss, & Sing, 2012). This study divided participants in groups with high and low scores on the "social skills" and "attention to detail" subscales of the Autism Spectrum Questionnaire (AQ), and the results surprisingly showed better performance on the EFT in people with higher scores on the "social skills" subscale, indicating that local bias found in this group can be explained primarily by social deficits. Overall, the findings indicate that local processing bias and systemising cognitive style can be found in typically developing people.

3.5.3. Socio-emotional characteristics of the BAP

Difficulties in social behaviour and various affective disturbances have been reported in parents and other relatives of autistic children. Relatives of individuals with autism show increased rates of affective disorders and social anxiety (Bolton, Pickles, & Murphy, 1998; DeLong & Nohria, 1994; Smalley, McCraken, & Tanguay, 1995), although it is not clear whether it represents the same genetic mechanisms like autism, or has different genetic or environmental causes (in Rutter, 2005). Bolton et al., (1998) suggested that their findings of a higher risk of affective disorders in parents of children with autism could not be explained solely by the stress caused by having a child with autism. Several studies showed that parenting stress and depression in parents of children with autism was directly affected by child symptom severity (Benson, 2006; Ingersoll & Hambrick, 2011). Ingersoll and Hambrick (2011) also found that parental expression of the BAP as measured by the Autism Spectrum Quotient (AQ) was associated with the use of different coping strategies, with higher AQ scores in parents associated with maladaptive coping strategies in comparison to parents with lower AQ scores. Piven et al., (1999) found higher rates of social and communication deficits and stereotyped behaviours and psychiatric disorders in relatives of individuals with autism (from multiple-incidence families) compared to families of individuals with Down's syndrome. Their results also suggested possible sex-specific differences in communication deficits, finding significantly higher rates of communication deficits in the autism mothers group compared to the Down's syndrome mothers group, who did not show communication

deficits. No significant differences between the rates of communication deficits were observed in the autism and Down syndrome fathers groups.

Szatmari et al. (2008) found a higher alexithymia trait among ASD parents than Prader–Willi Syndrome (PW, another developmental disability) parents, and the higher alexithymia scores among fathers was associated with higher symptom severity in repetitive stereotyped behaviours in children with ASD. Alexithymia is a dimensional personality trait describes individuals who have difficulties in understand the meaning of their own emotional feelings and also in verbally describing those feelings (Franz et al., 2008; Szatmari et al., 2008). Individuals with autism are found to be more alexithymic compared to typical controls (e.g., Tani et al., 2004; Hill et al., 2004).

Other social difficulties observed in parents of autistic individuals relate to a lower quantity and quality of friendships compared to parents of children with Down's syndrome (Piven et al., 1997; Santangelo & Folstein, 1995). Aloof personality and shyness were also frequently observed among relatives of autistic individuals (Piven et al., 1997). A lack of empathy was also reported in parents of children with autism (Wolff et al., 1988), particularly in fathers (Sucksmith, Allison, Baron-Cohen, Chakrabarti, & Hoekstra, 2013). Communication difficulties, particularly impaired pragmatic language use (social language use) was also found among relatives of autistic individuals (Landa et al., 1992; Piven et al., 1997).

3.5.4. Social cognition in the BAP

Several studies examined social cognition in the BAP. Baron-Cohen and Hammer (1997) used the Reading of the Mind with the Eyes test to examine theory of mind in parents of individuals with Asperger's syndrome (AS), and result revealed more difficulties in identifying thoughts and feelings based exclusively on eyes in AS parents, particularly fathers, compared to the age- and IQ-matched control group. Similar results were found by using a children's version of the Reading of the Mind with the Eyes test with non-affected siblings of children with Asperger's syndrome, indicating poorer performance on the theory of mind task in the sibling group (Dorris et al., 2004). Losh et al., (2007) divided parents of autistic individuals into "aloof" and "rigid" personalities and found that socio-cognitive ability as measured by the Eyes Test was not impaired for parents of autistic individuals in general, but was impaired among the subgroup of parents with "aloof" personality relative to the control group of parents of unaffected individuals and parents of individuals with Down's

syndrome, and also relative to parents of autistic individuals with no recognised aloof personality (but those classified as having "rigid" personality). This study also found that mild-social cognitive disorder in "aloof" parents was associated with their limited friendships and dysfunctional pragmatic language use, reflecting findings of an association between impaired social-cognition in autism with problematic social functioning and language impairment (Tager-Flusberg, 2000).

In another study, Losh et al., (2009) administered a set of tests that measured social cognition, executive functions and central coherence in individuals with autism and a typical control group, and also in ASD parents and a control group consisting of parents from intact families. Results indicated greater difficulty on ToM tasks for parents with "aloof" personalities compared to ASD parents with "rigid" personalities and control parents of typical individuals. No differences were found between those groups for tasks examining central coherence and executive functions, suggesting the importance of neuropsychological examination of social cognition in studies of the heritability of autism (Losh et al., 2009). Losh et al., (2009) selected measures of social cognition based on their evidence from lesion and functional magnetic resonance imaging studies linked with specific brain regions, most particularly with the amygdala. Based on the findings of those studies, they propose that the amygdala may have an important role in "the subtle social-behavioural manifestation of genetic liability to autism among unaffected relatives" (Losh et al., 2009, p. 524). The main conclusion of those studies is that the Eyes Test may represent an endophenotypic marker of socio-cognitive characteristics of the BAP, and is present among specific groups of parents with an "aloof" personality.

Di Michele et al., (2007) found poorer performance on false belief tasks and Gricean Maxims tasks (expression rules or maxims of conversation, with violations of those maxims creating the basis for inferences that we draw in conversation, which Grice called implicatures; Grice, 1957) in ASD parents compared to parents of children with Down's syndrome and the control group. This study also showed that ASD parents had similarities to autistic subjects in patterns of impairment in pragmatic communication that was found to be associated to ToM impairments, whereas parents of subjects with Down's syndrome did not show similarities in cognitive performance to their children (Di Michele et al., 2007). However, some studies did not show any difficulties with ToM in ASD siblings compared to siblings of individuals with other developmental disabilities (Ozonoff et al., 1993; Shaked, Gamliel, & Yirmiya, 2006).

The study by Losh et al., (2009) used the Point Light Displays test as one of measures of social cognition, and found that ASD parents belonging to the "aloof" group showed difficulties in judging the trustworthiness of stimuli. This group, compared to the control group of parents from intact families and ASD parents with no aloof personality, did not differentiate positive and negative valence of stimuli, rating them as neutral.

There are an increasing number of studies examining social cognition and social behaviour in typically developing individuals with high autistic traits, in most cases measured by the AQ. Those studies demonstrated, for example, that individuals with high AQ scores compared to those with low AQ scores show impaired implicit social learning (by employing a gaze-cueing paradigm) (Hudson, Nijboer, & Jellema, 2012), a decreased propensity for pro-social behaviour as examined by a novel scenario-based task describing everyday situations (Jameel, Vyas, Bellesi, Roberts, & Channon, 2014), a decreased sensitivity to nonverbal cues and difficulty with facial emotion recognition (Ingersoll, 2010), and also reported having shorter durations of friendships and greater feelings of loneliness (Jobe & White, 2007). Individuals with high autistic traits were also found to show longer latency, but normal accuracy during the Eye Test (Miu, Pana, & Avram, 2012). Based on findings of reduced spontaneous mimicry of social stimuli in people with autism (Chakrabarti & Baron-Cohen, 2006; Hermans, Putman, & Van Honk, 2006), several recent studies also demonstrated reduced spontaneous mimicry of socially rewarding stimuli, including happy faces (Sims, Van Reekum, Johnstone, & Chakrabarti, 2012) and human hands (Haffey, Press, O'Connell, & Chakrabarti, 2013) in neurotypical subjects with high autistic traits. Haffey et al., (2013) also showed a strong positive correlation between trait empathy as measured by the Empathy Quotient (EQ) and mimicry of human hands, but not of robot hands, indicating that mimicry of social stimuli is modulated by the level of empathy. As this study did not find correlation between autistic traits and mimicry, it was also suggested that deficits in the neural mechanism of mimicry could not be associated with autistic traits. However, findings of reduced mimicry in individuals with high autistic traits is consistent with the reduced reward system found in autism (Dawson et al., 2005; Kohls et al., 2011; Scott-Van Zeeland et al., 2010). In a fMRI study that examined the functional connectivity between brain regions involved in processing happy versus low reward happy faces, Sims, Neufeld, Johnstone and Chakrabarti (2014) found greater functional connectivity between the ventral striatum (VS) and inferior frontal gyrus (IFG), and this connectivity was correlated negatively with the AQ scores. The authors suggest that reduced mimicry for socially rewarding stimuli in individuals

with high autistic traits, as found previously in electromyography (EMG) studies (Haffey et al., 2013; Sims et al., 2012), can be explained by atypical connectivity between brain regions associated with mimicry and social reward.

In face perception research there has been strong evidence for similarities between parents and siblings of individuals with autism and individuals with the disorder in relation to gaze patterns as examined by eye-tracking. Those studies showed fewer fixations to the eyes and enhanced processing of the mouth in both individuals with autism and their siblings (Dalton, Nacewicz, Alexander, & Davidson, 2006) and in parents of individuals with autism with "aloof" personalities compared to a control group of parents of non-autistic children and parents of children with autism but with non-aloof personalities (Adolphs, Spezio, Parlier, & Piven, 2008). Scheeren and Stauder (2008) examined visual orienting to social (eyes) and non-social (arrows) cues and found slower responses to social cues in fathers or children with autism compared to control fathers, with no differences found between groups of mothers. This result is explained by slowed attention orienting in autistic fathers, possibly because of their narrower focus of attention, and this behaviour was compared to inflexible behaviour found in autism. There has been some support for atypical gaze patterns with decreased eye contact in infant siblings who are at risk of autism (Merin, Young, Ozonoff, & Rogers, 2007; Young, Merin, Rogers, & Ozonoff, 2009). However, it has been also shown that atypical gaze behaviour found in 6 month old infants did not result in autism 18 months later, suggesting that gaze behaviour is not an early marker of autism (Young, Merin, Rogers, & Ozonoff (2009). Altogether, findings about atypical gaze processing in siblings and parents of individuals with autism suggest that eye fixation can be useful for isolating the genes that contribute to social deficits in autism (Adolphs et al., 2008; Dalton et al., 2006).

Several studies also indicated that relatives of individuals with autism experience difficulty in face perception. Wilson, Freeman, Brock, Burton and Palermo (2010) examined face recognition in children with autism and their parents, including both the mother and father of a child with ASD, compared with typically developing control groups. Participants were administered face recognition tasks including the Cambridge Face Memory Test (CFMT) that measures the recognition of previously seen facial identities, and tasks that required sequentially matching facial identity and shoes. This study demonstrated an impaired performance of parents with autistic children on the CFMT, particularly fathers, but no difference between autistic parents and the typically developing control group was found on matching tasks. The BAPQ questionnaire (Hurley et al., 2007) was also administered in that

study to measure autistic traits in participants, but no significant correlation was found between expected aloof personalities in parents and face identity, and the authors concluded that the previously found association with aloof personality (Adolphs et al., 2008) and facial emotion perception does not apply to perception of facial identity. However, autistic children's performance on the sequential matching task was significantly correlated with performance of the mothers, which is explained by the smaller number of fathers in the study. Similarly, Wallace, Sebastian, Pellicano, Parr and Bailey (2010) examined face processing in parents and adults siblings of individuals with ASD, adults that have ASD, and typically developing adults. Participants were compared on their performance in three face processing tasks, including one that examined subtle differences between face and non-face stimuli that varied in configural and featural characteristics, one that was a facial emotion recognition task, and one requiring discrimination of the direction of social (eye-gaze) and non-social (arrow) cues, with eye-gaze embedded in a whole face or eye-region presented alone, to test the effect of holistic processing. The results of this study showed that compared to typically developing participants with no autistic relatives, the relatives of people with autism showed difficulty in recognising subtle differences between faces, but not objects, and also difficulty in identifying facial expressions of fear and disgust. Autistic relatives did not show an advantage for direct compared to averted eye-gaze direction, similar to adults with ASD. However, they showed holistic processing strategies during judging gaze direction that differ from strategies used by subjects with ASD (Wallace et al., 2006). Dawson et al., (2005) also found reduced face recognition ability in parents of children with autism, relative to their visual spatial and verbal abilities. Parents of children with autism also showed atypical ERPs to faces, showing slower neural processing of faces as indicated by the face specific ERP component, N170, which was not found to show shorter latencies for faces compared to objects in parents of children with autism. This group also did not show right hemisphere lateralisation for face stimuli.

Dalton et al., (2006), besides finding atypical gaze patterns in autistic siblings, also found that siblings, similar to individuals with autism, showed hypoactivation in the right fusiform gyrus and reduced amygdala volume during face processing. Similarly, Spencer et al., (2011) also found atypical brain activation in unaffected siblings, with significantly reduced fMRI responses to happy compared to neutral faces in brain areas associated with empathy and facial emotion processing. This study did not find differences in brain activation between unaffected siblings and individuals with autism, but significant differences were

found between siblings and control group participants. However, Rojas et al., (2004) found normal amygdala volume in parents of individuals with autism, suggesting that atypical social brain activation in relatives of individuals with autism is not uniformly supported across studies. As the majority of participants in this study were mothers, and female relatives of individuals with autism are found to be less affected by the BAP (Constantino & Todd, 2003), this study should be replicated with a more balanced number of mothers and fathers. Rojas et al., (2004), however, demonstrated a larger volume of the left hippocampus in both the parents of children with autism and adults with autism compared to the neurotypical control group without familial history of autism.

3.5.4.5. Social cognition and autistic traits

Recently, some evidence has emerged for atypical social cognition in individuals with higher autistic traits. Studies have demonstrated that individuals with higher AQ scores had slower response times during a visual perspective taking task that required understanding the perspective of others (Brunyé et al., 2012), and also performed more poorly in understanding social acting stories that requires understanding everyday social interaction (Yang & Baillargeon, 2013). Related to those findings are two studies (Swanson, Serlin, & Siller, 2013; Swanson & Siller, 2014) that examined eye-gaze allocation in typically developing children and adults, with results showing that individuals with higher autistic traits failed to modulate their gaze according to the experimental condition (gazing at a target versus gazing elsewhere).

Differences in brain activation were also found between neurotypical subjects with high and low autistic traits as measured by the Autism Spectrum Quotient (AQ). For example, von dem Hagen et al. (2011) employed voxel-based morphometry and showed decreased white matter volume in the posterior superior temporal sulcus (pSTS) in subjects with high AQ scores. A recent near-infrared spectroscopy (NIRS) study showed that whereas the PFC and STS were significantly activated during the viewing of conversations between two people, typically developed individuals with higher autistic traits (especially males) had less brain activation in the left pSTS (Suda et al., 2011). Participants with high autistic traits (AQ) were also found to have less activation to slow, affective touch in the right STS and the right OFC (Voos, Pelphrey, & Kaiser, 2013). High AQ participants in this study also showed less preference for social touch. Correlation between autistic traits (AQ) and activity in the pSTS was also found during direct gaze perception, but no correlation was found between activity

in the MPFC and autistic traits (Hasegawa et al., 2013). Wallace et al., (2012) found an association between higher autistic traits as measured by the SRS and a thinner cortex predominantly in the right STS, and in contrast higher antisocial traits were found to be associated primarily with a thinner cortex in bilateral anterior prefrontal cortices. Altogether, these studies show significant association between autistic traits and the social brain, particularly STS, a region found to be important in various social processes that include the understanding of intention (Pelphrey, Morris, & McCarthy, 2004b). Another important finding related to social brain is the differences between individuals with high and low autistic traits in human mirror neuron systems (hMNS) activation (Cooper, Simpson, Till, Simmons, & Puzzo, 2013) Cooper et al., (2013) found greater hMNS activation to negative facial expressions in individuals with higher autistic traits, and greater activation to positive (happy) faces in individuals with low autistic traits.

Additionally, several studies have demonstrated atypical brain connectivity in typical subjects with higher autistic traits. For example, a resting state functional connectivity of the anterior mid-insula with the pregenual anterior cingulate cortex was found to be negatively correlated with scores on the Social Responsiveness Scale - Adult Version (SRS-A), indicating negative connectivity between these two regions and high autistic traits (Di Martino et al., 2009b). The pregenual anterior cingulate cortex is found to be significantly associated with the theory of mind (Amodio & Frith, 2006; Gilbert et al., 2006) and hypoactivated in individuals with autism during social processing (Di Martino et al., 2009a). Recently, it was also demonstrated that the better the connectivity of the social brain with others when viewing naturalistic social interactions, the lower the AQ score in neurotypical participants (Salmi et al., 2013). This study demonstrated that, by using a seed-voxel based correlation analysis, there was atypical connectivity of the frontal pole with cingulate, superior frontal, and posterior parietal cortices in individuals with ASD.

Several other recent studies that examined brain structures in neurotypical individuals with high autistic traits demonstrated that strong autistic traits (AQ) were correlated with smaller regional grey matter volume in the right insula, with this correlation especially pronounced for males (Saito et al., 2013).

3.6. Summary

Twin studies, family studies, and investigations of syndromes and chromosal disorders have positioned autism as a strongly hereditary disorder. However, the exact genes and

patterns of heredity are not clear. A great number of recent studies have shown that parents and siblings of individuals with autism have characteristics similar to individuals with autism, although in milder measure, which belong into the BAP. Similarly, a greater number of studies have started examining autistic traits in the general population, predominantly using the Autism Spectrum Quotient (AQ) for measuring autistic traits. In recent years there has also been an increase in studies examining the brain activity characteristics of relatives of individuals with autism and individuals with higher autistic traits. Many of these studies have established the measure of an atypical social brain in autistic relatives and individuals with higher autistic traits, particularly STS, but there is scarce data on other regions, particularly the amygdala. Although some studies that directly measured the amygdala did not show its impairment in parents of individuals with autism, evidence of the absence of an attention to emotion bias in typically developing individuals with high AQ (Miu et al., 2012) scores suggests a similar emotion-attention dysfunction observed previously in autism (Ashwin, Wheelwright, & Baron-Cohen, 2006; Uono, Sato, & Toichi, 2009). As emotion-attention dysfunction was suggested to have a source in the early amygdala dysfunction in autism (Schultz, 2005), this finding could indicate a possible amygdala impairment in typical individuals with high autistic traits (Miu et al., 2012).

One important consideration for future BAP examinations may be more careful investigation of sex-specific differences in the expressions of the BAP in parents and siblings. Sex differences in parents on various social and non-social tasks have already been found. Several studies reported greater difficulties in fathers of autistic individuals in central coherence tasks and social cognition tasks (Happé et al., 2001; Wong et al., 2006). In one rare study that did not find higher impairments in fathers, Piven et al., (1997) reported higher rates of communication difficulties in mothers of autistic individuals, with difficulty being absent in the comparison group of mothers of individuals with Down's syndrome. Significant communication difficulties were not found among fathers, although the authors explain this as being due to the small sample size and limitations of the family history method employed. Those findings show the need for a sample that includes a balanced number of male and female relatives/participants. It can also be said that most of studies that examine autistic traits in the general population often do not report sex differences.

Autistic traits are sometimes described as extreme male traits, and related to prenatal exposure to high testosterone levels (Barbeau, 2009). This description is consistent with Baron-Cohen's group theory of autism as being an extreme form of the typical male brain

(extreme male brain (EMB) theory: Baron-Cohen, 2002). According to the EMB theory, people with autism show high performance levels on tasks that men usually excel at and have greater difficulty on tasks usually performed better by women. However, recent evidence does not support this view, as it shows that people with autism can achieve good results on tasks at which women are typically better than men. For example, Jemel, Mottron and Dawson (2006) reviewed behavioural, ERP and functional imaging evidence of impaired face processing in autism suggesting that there is not strong empirical support for claiming impaired face professing in the disorder. In addition, Scheeren and Stauder (2008) did not find significantly higher AQ scores in parents of children with autism, which questions the sensitivity of this instrument for measuring autistic traits in the general population, although higher scores were found for fathers compared to mothers. In sum, although in recent times the understanding of heredity factors in various impairments in autism has improved, there are still many unanswered questions. In particular, further studies that examine neurotypical individuals with higher and lower autistic traits can enhance our understanding of autism.

CHAPTER 4 –

METHODS: ELECTROENCEPHALOGRAPHY (EEG)
AND MAGNETOENCEPHALOGRAPHY (MEG)

4. Basics of EEG and MEG

Electroencephalography is traditionally described as "the electrical activity of the brain recorded from the human scalp" (Lopes da Silva et al., 2009). This is the translation of the term *elektrenkephalogram*, coined by Hans Berger (1873-1941), a German researcher who conducted the first EEG recordings using scalp electrodes (in Keil, 2013). Although there are some other powerful techniques for imaging functional states of the brain, such as fMRI and PET, the EEG occupies an important position because of its main characteristics. One of those characteristics that puts the EEG in a direct advantage in comparison to other techniques is that electrophysiological time series are a direct reflection of neuro-electric processes, compared to blood flow (such as functional magnetic resonance, fMRI) or metabolic processes (such as positron emission tomography, PET) (Keil, 2013, p. 109). Several other important characteristics of the EEG give it an important place as a research and diagnostic tool. One of them is an exceedingly high time temporal resolution of 1 ms or even better under optimal conditions (da Silva, 2009; Luck, 2005). In contrast, hemodynamic measures have poor temporal resolution of several seconds due to the slow hemodynamic response. However, hemodynamic measures have a much better spatial resolution (in the millimeter range). It is generally considered that the ERP technique has a poor spatial resolution, although Luck (2005) mentions that its spatial resolution is basically undefined, because a pattern of ERP data can be explained by "infinitely many ERP generator configurations" (p. 25).

Another important characteristic of the ERP technique is that it is completely non-invasive. This means that there is no restriction of the number of testings with a single subject. Contrary to this, the PET technique is quite invasive and therefore a very limited amount of data that can be collected from each subject. ERPs are also inexpensive in comparison with other techniques, especially compared to MEG, and simple to record. Finally, it is the only technique that can be used with a freely moving subject (Lopes da Silva, 2009). Magnetoencephalography or MEG shares the first two of these characteristics with the EEG, although not the last one. MEG records the rapidly changing magnetic field produced by brain activity. It is non-invasive and has relatively high spatiotemporal resolution. An important advantage of MEG is "that magnetic signals are much less dependent on the conductivity of the extracellular space than EEG" (Buzsáki, Anastassiou, & Koch, 2012, p. 409).

4.1. Neurophysiological sources of EEG and MEG

The ERPs predominantly reflect postsynaptic potentials rather than action potentials, with postsynaptic potentials arising relatively more slowly than action potentials (Luck, 2005). The synaptic activity involves both excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs). The source of the EEG and MEG is the synchronised activity of thousands to millions of cortical pyramidal cells, although MEG is considered to be more sensitive to a smaller number of neurons (Keil, 2013). The majority of electromagnetic activity is due to synaptic activity at dendrites. An example in **Figure 1** shows possible bio-psychological events that result in scalp ERPs (Luck, 2005). When an excitatory neurotransmitter is released at the apical dendrites of a cortical pyramidal cell, positive ions will start flowing into postsynaptic neurons. A net negativity will be created ("-" symbols) at the apical dendrites, generating a small dipole. A current will also flow at the distal part of the cell (body and basal dendrites), generating a net positivity. "Together the negativity at the apical dendrites and the positivity at the cell body create a tiny dipole (a dipole is simply a pair of positive and negative electrical charges separated by a small distance)" (Luck, 2005, p. 29).
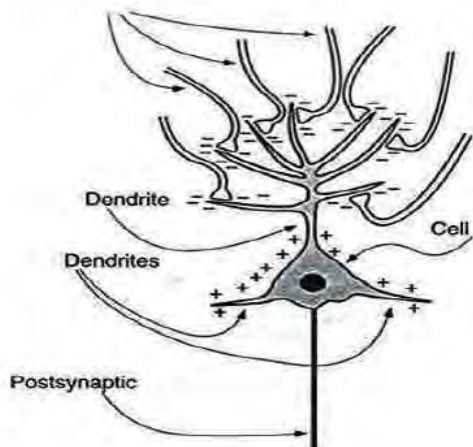
Figure 4-1: Schematic pyramidal cell during neurotransmission (from Luck, 2005, p. 30).

The dipole from a single neuron is too small and therefore cannot be recorded from a distant scalp electrode (Luck, 2005). However, the dipoles from numerous neurons will summate and only this summated voltage will be recorded at the scalp. Dipoles will summate and are able to be recorded from the scalp only if dipoles occur at approximately the same time across thousands or millions of neurons, and if all neurons have a similar orientation and receive the same type of input.

Difficulties in the summation of the individual dipoles may be created by the physical properties of the cortex (Luck, 2005). In the scalp-recorded EEG, underlying voltage gradients are altered by the different types of tissue that the current passes through (e.g., brain, skull, skin, etc.). In contrast, MEG is not mediated by volume conduction, as the skull is transparent to magnetism, making MEG sensitive to original cellular events (Keil, 2013; Luck, 2005). In this way, MEG has a much greater spatial resolution than EEG. One important reason for low spatial resolution of the EEG is that the skull acts as a low-pass filter and will introduce artificial correlations between the electrodes (Srinivasan, Nunez, & Silberstein, 1998; Srinivasan, Nunez, Tucker, Silberstein, & Cadusch, 1996)

Another important difference between EEG and MEG is that EEG is more sensitive to radial generators and MEG is more sensitive to tangential generators as MEG studies have a bias towards cortical sulci (Keil, 2013). This characteristic of MEG is a consequence of a magnetic field, which is oriented orthogonal to the generating electric field. Another explanation is that, due to a near-spherical shape of the brain, "sources oriented radially to the scalp surface generate only very weak magnetic field gradients outside of the skull" (Keil, 2013, p. 110).

4.2. EEG/MEG: Instrumentation

MEG systems contain a dense array of sensors within a large vacuum flask (Dewar) that contains superconducting quantum interference devices (SQUIDs) immersed in liquid helium (Keil, 2013). When cooled to the temperature of liquid helium, a SQUID can carry electricity without resistance, allowing it to measure the magnetic interference induced at coils within the MEG helmet. Modern MEG helmets allow recording of the whole brain's magnetic field pattern with more than 300 SQUID sensors (Hari, Levänen, & Raij, 2000). The MEG signals are usually shown in the femptotesla (10^{-15} Tesla) range. The MEG recordings are typically carried out in a magnetically shielded room to avoid contamination by external artifacts. EEG consists of electrodes placed over various locations on the scalp, mostly comprising sensors involving silver-silver-chloride contact that is filled with conductive paste, although often it also includes other methods, such as placing electrode contacts in a sponge, and bathing it in a saline solution (Ferre, Luu, Russell, & Tucker, 2001; Keil, 2003).

One important difference between EEG and MEG concerning the recording methodology is that EEG needs a reference sensor. EEG voltage, as measured by EEG, is

measured with respect to one or more reference electrodes, whereas in MEG both magnetometers and gradiometers measure magnetic field/gradients at a given location, and therefore MEG does not need an external reference as EEG (Keil, 2003).

4.3. EEG/MEG rhythms

Both EEG and MEG recordings show activity at hundreds of thousands of cortical neurons. The activity of those neurons is interdependent and oscillatory, and its composition frequency can be changed over time, depending on subjective or external conditions (Keil, 2013). Oscillatory activity of neuronal populations of neurons comprises both excitatory and inhibitory connections.

Brain oscillation analysis is popularly useful in emotion research. It is considered that time-frequency analysis (Tallon-Baudry & Bertrand, 1999) may be better in recognising rapidly changing overlapping neural oscillations during emotional processing than spectral analysis. Time-frequency analysis allows studying changes of the signal spectrum over time, and not necessarily time- and phase-locked to an event (i. e. evoked activity). For example, ERP measures time- and phase-locked events. In contrast, time-frequency analysis enables analysis of both the power and changes in the phase (Keil, 2013). In sum, time-frequency analysis averages frequencies across all events, and therefore is sensitive to both induced and evoked neuronal activity. A method that was shown to be useful for implementing time-frequency analysis is the Wavelet transform that allows the use of different temporal resolution across different frequencies (Tallon-Baudry & Bertrand, 1999). A particularly popular wavelet in research is the continuous Morlet wavelet, "a sine wave segment multiplied by a Gaussian window function that is dilated and extended to be sensitive to different frequencies" (Keil, 2013, p. 119). Morlet wavelets have a high temporal sensitivity in the upper spectral range, allowing the identification of brief epochs of high frequency oscillations (above 20 Hz). Besides measuring spectral power over time, wavelets also have the possibility of quantifying the intertrial phase-locking of the neural oscillations (Keil, 2013).

EEG/MEG signals vary from low to high frequencies and are divided in several frequency bands named after Greek letters: δ (delta) = below 3.5 Hz, θ (theta) = 4-7.5 Hz, α (alpha) = 8-13 Hz, β (beta) = 13-30 Hz, and γ (gamma) = above 30-35 Hz (Lopes de Silva, 2009). The α rhythm differs according to the brain area and behavioural state. The α rhythm

at posterior regions (occipital, parietal, and posterior temporal areas) occurs in a state of relaxed wakefulness, and is most pronounced when eyes are closed. It is attenuated when eyes are open and at a state of alertness, for example, during mental activities. There is a special rhythm that occurs within the α frequency range – μ (mu) rhythm. The μ (mu) rhythm occurs over the Rolandic or central area and is attenuated during mental intention to perform a movement or during contralateral movement. An additional rhythm within this range is the mid-temporal α rhythm occurring over the temporal lobe mostly in MEG recordings and attenuated by sound stimuli. In general, recent research on alpha oscillations indicate the importance of these rhythms not only in "idling", but also to a great variety of modulations related to affective, motor, and memory processes (Klimesch et al., 2006). The alpha range component of mu rhythm (8-12 Hz, and sometimes 8-13 Hz) that peaks around over central sensorimotor regions of the cortex. This rhythm has recently received considerable attention in autism research, as it is supressed during both action execution and action observation and is extensively examined in the context of mirror neuron theory (e.g., Hari et al., 1998; Oberman et al., 2005), particularly in support of the broken mirror hypothesis in autism that is based on abnormal mu suppression in autism during action observation (Oberman et al., 2005). Another rhythm that also received attention as an index of mirror neuron activation is the sensorimotor beta rhythm that peaks around 20 Hz, but its atypical activation in autism is inconclusive (e.g., Avikainen et al., 1999; Honaga et al., 2010).

It has been proposed that neuronal synchronisation and/or de-synchronisation of the gamma rhythm is important for various cognitive processes, as indicated by a recent review of MEG studies (Jensen, Kaiser, & Lachaux, 2007). The gamma rhythm has been also shown to be important in the processing of facial emotional expressions, particularly in visual processing of threatening stimuli (e.g., Luo, Holroyd, Jones, Hendler, & Blair, 2007; Luo et al., 2009; Maratos, Senior, Mogg, Bradley, & Rippon, 2012). A recent MEG study found, for example, reduced gamma band activity in visual cortex for threatening facial expressions, particularly angry faces (Maratos et al., 2012). Gamma band activity was also found to be increased during presentation of supraliminal compared to subliminal facial expressions, suggesting that the gamma rhythm may be considered as a marker of consciousness (Balconi & Lucchiari, 2008; Luo et al., 2009). Recently it was proposed that induced gamma band rhythm (iGBRs) may have a crucial role in face processing, alongside with the face specific N170 ERP component (Dobel, Junghöfer, & Gruber, 2011; Zion-Golumbic, Golan, Anaki, & Bentin, 2008). iGBRs differ from the N170 in showing increased activation in response to

upright compared to inverted faces (Keil, Müller, Ray, Gruber, & Elbert, 1999) and to familiar compared to unfamiliar faces (Anaki, Zion-Golumbic, & Bentin, 2007).

"Evoked" or phase locked and "induced" or non-phase-locked gamma activity are considered to represent different neuronal processes (Tallon-Baudry & Bertrand, 1999). Evoked oscillations are tightly phase-locked to the stimulus, whereas induced oscillations are time-locked, but not phase-locked to the stimulus (Kinsey, Anderson, Hadjipapas, & Holliday, 2011; Roach and Mathalon, 2008). Differences between them are seen in the order of trial averaging and spectral analysis (David, Kilner, & Friston, 2006). In order to calculate evoked power, the MEG/EEG signal is first averaged over trials and then time-frequency analysis is performed to obtain an event-related response. In order to calculate induced oscillations, the time-frequency decomposition is first performed on each trial and only after that is averaging across trials obtained. Evoked power and background components are removed from measures of total power to reveal induced power (David et al., 2006; Rach and Mathalon, 2008). Activation of induced gamma activity is thought to be necessary in sensory feature binding. Of particular relevance for autism research is conceptualisation of the gamma rhythm as a rhythm involved in holistic processing of stimuli or the perception of a whole or gestalt. This rhythm is found to be increased in the visual cortex during the perception of coherent objects and coherent motion (e.g., Müller et al., 1996; Tallon, Bertrand, Bouchet, & Pernier, 1995; Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1996). A gamma increase has also been observed over frontal regions in response to tasks that require, for example, processing of upright faces (Keil, Müller, Ray, Gruber, & Elbert, 1999) and affective images (from the International Affective Picture System) (Müller, Keil, Gruber, & Elbert, 1999). Abnormal induced gamma band activity has been found in people with autism during the processing of upright and inverted faces (Grice et al., 2001). Grice et al. (2001) found increased gamma band activity in typical subjects for upright faces compared to inverted faces, whereas subjects with autism did not show differences in gamma band activity in response to upright and inverted faces. This result is interpreted as decreased perceptual binding in people with autism. Several studies also showed abnormal induced (Brown, Gruber, Boucher, Rippon, & Brock, 2005) and evoked (Stroganova et al., 2012) gamma band activity in children with autism in response to Kanizsa stimuli (i.e. geometric shapes that require visual binding). Atypical transient auditory gamma-band responses have been also observed in parents of individuals with autism, with increased induced gamma rhythm in both individuals with autism and parents of individuals with autism compared to controls,

and reduced evoked gamma-band rhythm in those groups compared to the control group (Rojas, Maharajh, Teale, & Rogers, 2008).

4.4. Event-Related Potentials (ERPs)

Event-related potentials (ERPs) reflect brain electrical activity occurring within a number of EEG epochs (or particular time periods) that are time-locked to a specific stimulus or event (Kuperberg, 2004; Nelson & McCleery, 2008). Each epoch is averaged, which eliminates the background EEG rhythms and background noise not related to the specific stimulus or event, allowing the signal to emerge from the background. This allows formation of positive and negative polarity, also called components, and each component is considered to reflect a particular neural generator subserving different neural and cognitive/perceptual processes. However, it is suggested that various ERP components may be a combination of electrical activity of several neuronal sources (Kuperberg, 2004). Thus, ERP components are defined by their polarity (positive or negative), latency, and scalp distribution within specific temporal windows of the ERP waveform. An advantage of ERPs is that they are time-locked to a specific stimulus, and therefore can be measured even without an overt response from the subject. However, it is not yet sure what exactly the ERP peak represents – the onset or the end of a cognitive process? Furthermore, the question remains whether waveforms seen on the surface of the scalp are precise indicators of neurocognitive processes (Kuperberg, 2004). However, the technique is much advanced now allowing the use of higher-density arrays of electrodes. This allows greater spatial sampling that, in turn, has numerous benefits: it permits identifying a greater number of components, better distinguishing of components, and also improves source modelling/localisation. Some dense arrays systems can be put on easily and quickly, which may be helpful for testing with special groups, such as infants and other difficult-to-test populations, especially children (Nelson & McCleery, 2008).

Various ERP components reflect some specific cognitive, perceptual and attentional processes and it is thought that earlier deflections after stimulus onset represent automatic psychological processes (Amodio, Bartholow, & Ito, 2013). There are numerous psychological processes that have been given attention in ERP research, and in social neuroscience special attention has been given to faces and facial emotion processing. ERPs have also been used to investigate the neural sources of impairments in autism, predominantly auditory, but recently also more in visual and particularly social processing (review in Jeste & Nelson, 2008). The review in this chapter will mostly focus on ERPs in

visual processing, with an overview of the most important components examined in socio-emotional processing (particularly face processing), and their findings related to subjects with autism. The majority of research in socio-emotional processing is focused on face processing, and therefore this chapter will mostly describe major ERP components in processing facial stimuli, including facial emotional expressions.

4.5. ERP Components

The review of ERP components will focus on description of the most important early and later ERP components involved in social cognition and face processing. As the N170 is thought to represent face specific component, its role in autism is particularly important and therefore will be discussed in greater detail later in this chapter.

4.5.1. Early components

N1 and P100

Early endogenous components are usually examined in studies interested in the extent of attention given to the stimulus early in processing (Bartholow & Amodio, 2009). Specifically, the N1 and the P100 have been associated with attentional processes, with larger amplitudes representing increased attention to the stimulus (Bartholow & Amodio, 2009). The N100 (and its magnetic equivalent, the M100) usually peaks between 60 and 160 ms and is considered to be an index of basic sensory (mainly auditory) processes (e.g., Bomba & Pang, 2004; Jeste & Nelson, 2009). Individuals with autism were found to have atypical N100 compared to controls (Courchesne, Lincoln, Kilman, & Galambos, 1985; Strandburg et al., 1993), although there are more findings of no differences between autistic and typical groups on this component (e.g., Larson, South, Krauskopf, Clawson, & Crowley, 2011; Tecchio et al., 2003). One of explanations for possible atypical N100 in autism is that it may be a consequence of difficulties in attention to stimuli, as attention difficulties are often observed in autism (e.g., Ceponiene et al., 2003). Differences between typical controls and autistic subjects on this component are seen in absent asymmetry in M100 generator location in autistic subjects (Schmidt, Rey, Oram Cardy, & Roberts, 2009). That is, generator location of the M100 in typical controls is more anterior in the right hemisphere than the left hemisphere (Elberling, Bak, Kofoed, Lebech, & Saermark, 1982). However, this asymmetry was found to be absent in autistic children (Schmidt et al. 2009).

Another early component, the P100, peaks between 120 and 180 ms, and is typically considered to represent an early occipital component (Batty et al., 2011; Di Russo, Martínez, Sereno, Pitzalis, & Hillyard, 2002; Kuefner, de Heering, Jacques, Palmero-Soler, & Rossion, 2010; Luo et al., 2010; Utama et al., 2009) and is thought to originate from striate and extrastriate visual areas (e.g., Clark, Fan, & Hillyard, 1995; Di Russo et al., 2002). It is thought to reflect early visual processing of stimuli and it has been found to be larger for faces compared to non-face objects in both children and adults (e.g., Herrmann et al., 2005; Batty & Taylor, 2003), and also to have a shorter latency in response to faces than objects (Taylor et al., 2001). This component has also been found to be sensitive to the first order configural information, usually disrupted by face inversion (Halit, de Haan, & Johnson, 2000; Itier & Taylor, 2002; Taylor, Batty, & Itier, 2004b; Mercure, Dick, & Johnson, 2008). Some studies also indicated that the P100 is sensitive to attentional modulation (e.g. Jemel, George, Olivares, Fiori, & Renault, 1999; Rossion et al., 1999). A number of studies have reported effects of facial expression on the P100 (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Several studies on subjects with autism indicated an impaired P100 component in this group, although results are inconclusive. Recently Webb et al. (2012) showed the absence of differential P100 response in adults with ASD to inverted faces compared to upright faces, whereas typical controls showed differential responses to inverted compared to upright faces. However, both groups showed larger P100 and N170 amplitudes to faces compared to houses.

The N170

Previous research has found evidence for face-specificity in visual processing by indicating a negative even-related potential (ERP) averaging 170 ms post-stimulus onset to show shorter latencies and larger amplitudes in response to faces in comparison to other objects (Bentin & Deouell, 2000; Dawson et al, 2005; Eimer, 2000; Itier & Taylor, 2004a; McPartland et al., 2004; Rossion et al., 2000b). The N170 component and its MEG counterpart (M170) represent an early cortical marker of face processing in occipitotemporal areas (e.g., Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer et al., 2011). As several studies have failed to find modulation of this component by non-perceptual factors such as familiarity (e.g. Bentin & Deouell, 2000; Eimer, 2000; Henson et al., 2003) or repetition (e.g. Eimer, 2000) of faces, it is associated with automatic face processing that precedes the recognition of individual faces (Eimer et al., 2011). However, some studies have found familiarity effects with reduced N170 amplitude for familiar faces compared to novel faces

(George, Jemel, Fiori, & Renault, 1997; Jemel et al., 2003), although the opposite effects were also observed, indicating larger amplitude for familiar faces (Caharel, Poiroux, & Bernard, 2002). Several findings of repetition effects on N170, mostly at the right hemisphere (Campanella et al., 2000), or bilaterally (Guillaume & Tiberghien, 2001; Itier & Taylor, 2002), suggest that this component could be modulated by priming and learning. The amplitude of N170 was also found to be larger for objects of expertise, for example, for pictures of dogs or birds for dog or birds experts (Tanaka & Curran, 2001).

The N170 is generally associated with perceptual face processing stages, but it is not clear to what degree it is associated with configural face processing as opposed to individual face parts. Some studies found this component to be larger to isolated eyes than the full face, associating it primarily with the isolated face parts, particularly eyes (e.g., Bentin et al., 1996; Itier et al., 2007). However, other studies have found the N170 to be sensitive to configural processing of the whole face by showing that it is enhanced and delayed for inverted as compared to upright faces (e.g., Bentin & Deouell, 2000; Eimer, 2000c; Rossion et al., 2000b). Sensitivity of the N170 to face inversion was found as a strong support for showing that the N170 reflects early stage configural processing (e.g., Bentin et al., 1996; Eimer, 1998). Enhanced N170 amplitude by face inversion is explained by a difficulty in recognising inverted faces that require greater effort in order to be recognized (Marzi & Viggiano, 2007; Rossion et al., 1999; Watanbe et al., 2003; Sadeh, & Yovel, 2010). Itier et al. (2006, 2007) suggested that the face inversion recruits a neural system responsible for eye processing. According to this hypothesis, the source of the N170 is in the superior temporal sulcus (STS) region, which includes both eye selective and faces selective neurons. When faces are upright, the eye selective neurons are absent or less active, but when faces are inverted or eyes are presented in isolation, eye selective neurons become more active, probably because of face configuration interruption. Several other researchers suggest that the N170 is related to eye detection (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Dawson et al., 2005).

Most studies relate neural sources of the N170 activation to bilateral occipito-temporal cortex and posterior fusiform gyrus (e.g., Bötzel, Schulze, & Stodieck, 1995; Rossion et al., 2003) or posterior superior temporal sulcus (STS) (e.g., Itier & Taylor, 2004a). However, according to a new hypothesis this component reflects multiple neural sources (Eimer et al., 2011; Rossion & Jacques, 2008), and this is more in line with findings that suggest that the N170 is sensitive to both the configural face processing and the processing of individual facial features (Eimer et al., 2011).

There is conflicting evidence about whether the N170 is responsive to emotional expression. Whereas a number of studies have found that the N170 does not discriminate between emotional expressions (e.g. Eimer, Holmes, & McGlone, 2003; Herrmann et al., 2004), others have found that expression modulates N170 amplitude (Batty & Taylor, 2003; Caharel et al., 2002; Eger et al., 2003; Miyoshi, Katayama, & Morotomi, 2004). One of the rare studies that examined the N170 in facial emotional expression processing in development found increased N170s in response to negative facial expressions in adolescents over 14 years. However, no discrimination was found between positive and negative emotions in children under 14 for this component (Batty & Taylor, 2006). The authors suggested that the N170 is not sensitive to emotional expression in 4–6 year old children.

In addition, closely related to the N170 is the vertex-positive potential (VPP), typically observed over fronto-central sites between 140 and 180 ms following the onset of a face stimulus (Joyce & Rossion, 2005). It is proposed that the N170 and the VPP may be manifestations of the same neural generators due to their similarities in functional and temporal characteristics (Jeffreys, 1989; Joyce & Rossion, 2005; Rossion et al., 2003). For example, both of those components exhibit larger amplitudes to faces than to other objects categories (e.g., Bentin et al., 1996; Itier & Taylor, 2004a; Jeffreys, 1996; Rossion et al., 2000b, 2003). Joyce and Rossion (2005) showed that these two components represent two "flip sides" of the same underlying generators, but also warned that there may be additional generators, possibly unrelated to face processing *per se*, which may have a role in modulation of surface properties of one of those peaks (p. 2626). It is also proposed that the reference electrode location may influence what effects are observed for each component in a study (Joyce & Rossion, 2005). For example, it was found that the common average reference yielded the largest N170 amplitude and the smallest amplitude VPP (Joyce & Rosson, 2005). On the other side, averaged mastoid and also averaged sterno-vertebral non-cephalic references yielded the smallest peaks at N170 sites, with no significant difference between stimuli category (faces vs. other stimuli), and the largest peaks at VPP site, with significant differences between stimuli categories.

The N170 component in individuals with autism

Most studies on face processing in autism predominantly analysed early components. Decreased sensitivity of the N170 component to face inversion in individuals with autism has been reported in several studies (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004;

McPartland et al., 2011), although some studies suggest that individuals with autism show the typical N170 delay to inverted faces in comparison to upright faces, but that this effect may be reduced in people with autism (Churches, Baron-Cohen, & Ring, 2012a; McPartland et al., 2004). Delayed N170 latencies to faces compared to objects have also been observed in individuals with autism (Dawson et al., 2002; McPartland et al., 2004; O'Connor, Hamm, & Kirk, 2005, 2007; Webb, Dawson, Bernier, & Panagiotides, 2006), as well as first-degree relatives (Dawson et al., 2005; McCleery, Akshoomoff, Dobkins, & Carver, 2009), although some studies suggest at least partially preserved face perception in some subgroups of individuals with ASD (Webb et al., 2010, 2012). Some studies showed delayed latencies of both P100 and N170 ERPs in adults with autism (O'Connor et al., 2005, 2007), although several other studies failed to find group differences (Churches, Damiano, Baron-Cohen, & Ring, 2012b; Webb et al., 2012). Web et al. (2012) suggested that inconsistencies in findings may be due to methodological differences, particularly whether studies included a cross hair to guide attention as previous fMRI research found that activation of regions responsible for face processing were influenced by attention in individuals with autism (Dalton et al., 2005). However, some studies found reduced N170 latency in autism for both face and non-face stimuli suggesting slower general speed of processing in this group and not to face processing per se (Hileman, Henderson, Mundy, Newell, & Jaime, 2011).

Two studies (O'Connor et al., 2005; Wong et al., 2008) examined the P100 and the N170 components in response to emotional facial expressions in autism and did not find ERP differences between children with autism (high functioning children with autism and also with Asperger's) and controls for all facial expressions. However, Wong et al. (2008) applied source localisation and found delayed activation of cortical regions important for face processing in subjects with autism. As O'Connor et al. (2005) found significantly larger N170 amplitude and a significantly shorter N170 latency in typically developing adults compared to adults with Asperger's they suggested that their results indicate that the N170 differences between individuals with and without autism can be observed in adulthood but not in early childhood. In another study, O'Connor, Hamm and Kirk (2007) presented adults with Asperger's and a control with faces, eyes, mouths and objects in a task consisting of discriminating target and distracter stimuli. The findings of the study indicate no group differences on N170 amplitude, but a significantly shorter N170 latency to eyes and mouths for controls relative to adults with Apserger's.

4.5.2. Later ERP components

An early study found ERP differences between young 3- to 4-years old autistic and typically developing children (Dawson et al., 2002). This study found ERP amplitude differences at the posterior P400 and the frontal Nc components in typically developing children to an unfamiliar face as compared to a familiar (mother's) face, and also to a familiar compared to an unfamiliar object. Contrary to this, children with ASD did not show differential ERPs to familiar *cf* unfamiliar faces, but they did show differential ERPs responses at those components to a familiar compared to an unfamiliar object. Another comparison group in this study, developmentally delayed children, showed differences in the slow wave for both familiar faces and objects compared to unfamiliar stimuli. Previous studies with typical subjects found earlier activation of the posterior P400 for faces compared to objects, suggesting that this component has a temporal advantage in processing faces when compared to objects (de Haan & Nelson, 1999). The Nc, a component that is maximal over frontal midline electrodes, has been thought to be an index of increased attentiveness to salient stimuli (Courchesne, 1978) and recognition memory (de Haan & Nelson, 1997, 1999).

The P400 is a positive component maximal over posterior lateral electrodes whose peak latency decreases from approximately 450 to 390 ms between 3 and 12 months of age (de Haan, Johnson, & Halit, 2007). This component has been suggested as a precursor of the adult N170. Although it differs from the N170 in later latency and positive polarity, it is faster to faces compared to objects (de Haan & Nelson, 1999), and is also more prominent in lateral than medial electrodes (de Haan, Pascalis, & Johnson, 2002; Halit et al., 2003), making it similar to the N170. The P400 shows differentiation between upright and inverted face by 3 months of age, although this inversion is not similar to the inversion in the adult N170 as it is not specific to human faces (de Haan et al., 2002). However, by 12 months of age the longer latencies of P400 show inversion exclusively to human faces making it similar to the adult N170 (Halit et al., 2003). The negative central (Nc) component is another component found in infants, occurring between 400-800 ms after stimulus onset and is most prominent over frontal midline electrodes (de Haan et al., 2007). This component has been associated with allocation of attention, particularly to salient stimuli (Courchesne, 1978; Nelson, 1994; Swingler, Sweet, & Carver, 2010), and recognition memory (de Haan & Nelson, 1997, 1999; Nelson, 1994). The Nc component was found to be larger in response to familiar compared to unfamiliar faces and objects (de Haan & Nelson, 1997, 1999). The relationship between the Nc and the N170, including between the Nc and other components

elicited during processing of faces in adults, is unclear, since there are not studies in which infants and adults were tested under the same conditions with familiar and unfamiliar faces (de Haan et al., 2007). An additional component that is considered to be a developmental precursor of the N170 is the infant N290. The N290 is maximal over midline and paramidline posterior electrodes and its peak latency decreases from approximately 350 ms to 290 ms between 3 and 12 months of age (de Haan et al., 2007; Halit et al., 2003). Studies that implicated this component as a possible precursor of the adult N170 showed that the N290 was larger to faces than noise in 3-month-old participants, giving similar results to those found for the adult N170 under the same procedure (Halit, Csibra, Volein, & Johnson, 2004). This component also showed increased amplitudes for human but not monkey faces in participants at 12 months of age (Halit et al., 2003). The results of this study paralleled those found for the adult N170 under the same procedure (Halit et al., 2003).

Another component important for face processing in adults is the N250, a negative component peaking around 250 ms after stimulus onset and is maximal over lateral occipitoparietal sites (Churches et al., 2012). This component was found to be sensitive to repetition, familiarity and learning of faces (e.g., Itier & Taylor, 2004c; Jemel, Schuller, & Goffaux, 2010; Kaufmann, Schweinberger, & Burton, 2009; Nasr & Esteky, 2009; Pierce, Muller, Ambrose, Allen, & Courchesne, 2001; Tanaka et al., 2006; Webb et al., 2010), suggesting that this component is involved in processing facial identity (Webb et al., 2010). The N250 has also been suggested to be involved in the processing of configural relation of facial features as it was found that the N250 repetition effect was delayed for inverted faces (Itier & Taylor, 2004a). However, recent findings implicate the N250 (especially fronto-central N250) (Luo et al., 2010) in processing of higher-order visual information, such as facial emotional expressions (Balconi & Pozzoli, 2008; Carretie et al., 2001; Wynn, Lee, Horan, & Green, 2008). The N250 component in autism is not extensively studied. Recently, Churches et al., (2012a) examined the acquisition of new face representations in autism and the N250 was found to be reduced for target faces in adult participants with Asperger's, suggesting an impaired development of new face representations in this group. Contrary to this, Webb et al. (2010) did not find any difference between individuals with autism and a healthy control group on the N250 ERP.

The P300 (or P3) (M300 in MEG) component is observed around 300 ms post-stimulus onset and is thought to be an index of higher cognitive processing. It is often divided into the early P300a and the late P300b (Picton, 1992; Polich, 2007). The P300a is considered

to represent orientation to changes in the environment underlying attentional switching with sources in frontal regions (Jeste & Nelson, 2009; Knight, Grabowecky, & Scabini, 1995; Marco, Hinkley, Hill, & Nagarajan, 2011; Reviews in Polich, 2007; Polich & Criado, 2006), although there are reports of some more posterior areas of the brain playing some role in generation of this component (Halgren et al, 1995). On the other side, the P300b is associated with the task-relevance of stimuli, probably underlying working memory (Bomba & Pang, 2004; Marco et al., 2011) with sources in temporal and parietal regions (Knight, 1996; McCarthy, Wood, Williamson, & Spencer, 1989; Review in Polich, 2007; Polich & Criado, 2006). Traditionally, P300 (P3) is referred to the P300b. Reduced P300 has been observed in autism predominantly in response to auditory stimuli (e.g., Bomba & Pang, 2004; Courchesne et al., 1985; Dawson, Finley, Phillips, Galpert, & Lewy, 1988). Several studies reported reduced P300 in autism for visual stimuli (e.g., Verbaten, Roelofs, van Engeland, Kenemans, & Slangen, 1991), although there are studies that did not find this reduction (e.g., Courchesne, 1985; Sokhadze et al., 2009). Reduced P300 in autism is suggested to mean that this group have difficulties in prescribing significance to the target stimuli (Oades, Walker, Geffen, & Stern, 1988). However, Salmond, Vargha-Khademl, Gadian, de Haan and Baldeweg (2007) found reduced P300 in low-functioning individuals with autism, but not in high-functioning individuals with autism, suggesting that this component may be related to the cognitive abilities of participants.

A component that is thought to be important when studying facial processing is the P200. The P200 ERP has been found to be modulated by facial emotional expressions (Kolassa, Kolassa, Musial, & Miltner, 2007; Rossignol, Philippot, Bissot, Rigoulot, & Campanella, 2012), particularly in explicit emotion processing tasks, suggesting that this component is related to appraisal of the emotional relevance of the stimuli (Peschard, Philippot, Joassin, & Rossignol, 2013). It has been found to be particularly enhanced for pleasant compared to unpleasant stimuli (Carretié et al., 2004). Several studies found enhanced P200 to facial stimuli in individuals with social anxiety disorder (Rossignol et al., 2012; Peer et al., 2010; although this effect was absent in Kolassa et al., 2009; Kolassa & Miltner, 2006). It is interesting that there is a lack of research in autism with this component. Altogether, research on autism has neglected examining temporal aspects of emotion processing, shown by the lack of EEG studies on emotion processing in individuals with autism, with most emotion research in autism using fMRI.

4.6. Summary

In summary, both EEG and MEG are non-invasive techniques that can be used for measuring neural processing of various tasks and both provide excellent temporal resolution, with the most important difference between them being better spatial resolution in MEG, but EEG being much less expensive in comparison with MEG. EEG is extensively used in studying face processing in autism, and findings indicate that individuals with autism show impairments in both early (P100 and N170) and later (Nc) stages of processing of faces, and that this impairment can be observed in young children with autism. However, EEG studies with autism lack investigation of a greater number of components related to faces processing, besides the early ERPs (P100 and N170). It is particularly surprising to see a lack of examination of temporal processing of facial emotional expressions in autism in general, and particularly the P200 component and other components found to be important in facial emotional expressions. Research also indicates atypical gamma activity in individuals with autism (Grice et al., 2001), suggesting decreased perceptual binding in autism, which is in accord with observed reduced holistic/configural processing in autism. Atypical mu rhythms suppression is also observed in autism, although this needs further and more careful investigation.

CHAPTER 5 –

AIMS AND OVERVIEW OF THE THESIS

5. Aims and overview of the thesis

The main aim of this thesis is to examine social-emotional processing in the broad autism phenotype by looking at typically developing individuals with high and low autistic traits as measured by the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001), and also parents and adult siblings of individuals with autism (in one of experiments). It is suggested that the difficulties found in autism can be observed in milder form in the BAP. The thesis examines this through three experiments that tap into the two main theories of autism disorder that can explain social-emotional impairments in autism: perceptual and social orienting models of autism. The perceptual explanation of the disorder is focused on the local bias and/or global impairment, as explained by the WCC theory (Frith, 1989; Frith & Happé, 1994; Happé & Frith, 2006) and Enhanced Perceptual Functioning (EPF) theory (Mottron et al., 2006). Another theory that is social in nature states that individuals with autism differ from typically developing individuals by lacking motivation or attention for social relevant stimuli (e.g., Dawson et al., 1998). The social orienting model of autism suggests that atypical or delayed orienting towards social information in the disorder (Dawson et al., 1998) damages the ability to develop subsequent important social skills (Dawson & Lewy, 1989; Klin, 1991), including face processing (e.g., Celani, Battachi, & Arcidiacono, 1999). Impairment in face processing in autism still lacks a final conclusion, as some research proposes that it can have a cause in the perceptual features of faces, rather than social orienting (Turati, 2004).

The first experiment (chapter 6) examined the processing of facial emotional expressions by using event-related potentials (ERPs). Based on findings of an atypical face inversion effect in individuals with autism (e.g., Langdell, 1978; Hobson et al., 1988b; Rose et al., 2007), this experiment examined whether differences in processing inverted faces could be seen in individuals with high and low AQ. Based on literature reviews (chapters 1-2), it was predicted that individuals with high AQ would show a reduced face inversion effect, particularly on ERP components (namely P100 and N170) previously recognised to show atypical activation during face inversion processing in subjects with autism. This proposition is based particularly on local bias and/or the lack of global precedence bias in this disorder, as explained by WCC and EPF theories. Examination of the modulation of facial expressions by face inversion was exploratory as there are not many studies that have examined this modulation in healthy individuals (Ashley et al., 2004), and even less in individuals with autism.

In the second experiment (chapter 7), subliminal and supraliminal facial expressions were examined in individuals with high and low autistic traits, again by using ERPs. In this experiment, emotional facial expressions – neutral, happy and fearful – were presented below the threshold of visual awareness and then masked by an abstract pattern. This study is based on proposals that subcortical routes support a rapid, automatic face detection system, and that early disorder of subcortical structures may lead to reduced social orienting in autism (Kleinhans et al., 2011).

The third experiment (chapter 8) examined biological motion processing in individuals divided into high and low AQ groups, and in a group of parents and adult siblings of individuals with autism. Biological motion stimuli are special stimuli created by combining point light dots representing various human-like movements (or actions). Stimuli used in the present study are point-light displays (PDLs) of human bodies representing various movements that are affectively laden (with happy and fearful emotions). In addition, scrambled PDLs and moving circle stimuli were also used.

Recognising biological motion from point light dots requires integrating single dots into a global whole, a task that may be difficult for individuals with autism due to their preference for local information (Frith, 1989). Biological motion research with autism is inconclusive (e.g., Blake et al., 2003), with some research showing that although autistic subjects may be able to recognise biological motion stimuli, they have difficulty in recognition when emotion is expressed (Hubert et al., 2007; Moore et al., 1997). This study applied MEG to examine alpha and beta decreases over regions implicated in the MNS, but also taking in account local and global visual processing by using point-light displays as stimuli. Examining alpha and beta suppression over the sensorimotor cortex with MEG is proposed to be an index of the MNS (Salmelin & Hari, 1994). Based on that, it is proposed that smaller alpha and beta decreases would be found for individuals with high AQ and also for first-degree relatives of individuals with autism. The MNS theory suggests that people with autism have atypical activation of the MNS during observation of movements representing actions (e.g., Dapretto et al., 2006), and this may be particularly pronounced for action requiring the attribution of mind reading to stimuli, such as reading emotions and intentions, which is a difficulty commonly found in this disorder (e.g., Baron-Cohen et al., 1985).

CHAPTER 6

EXPERIMENT 1:

Neural Correlates of Upright and Inverted Faces in Individuals with High and Low Autistic-Like Traits

6.1. Introduction

Facial perception, especially rapid recognition and interpretation of facial expressions, are essential for social communication and healthy social development. It has been suggested that processing of faces is highly specialised and qualitatively differs from processing of non-face objects (Eimer, 2000). Facial emotion processing has been given extensive attention in neuroscientific research, predominantly because of its importance for normal social functioning, and also because it has been implicated in various disorders, including Autism Spectrum Disorder (ASD). Although many studies have confirmed difficulties in face recognition in this disorder, including eye gaze, facial identity, gender, and recognition of facial emotional expressions (Best, Minshew, & Strauss, 2010; Dawson, Webb, & McPartland, 2005; Klin et al., 2002; Senju, Tojo, Dairoku, & Hasegawa, 2004; Senju, Yaguchi, & Tojoc, 2003; Teunisse & DeGelder, 1994), findings are not conclusive (e.g., O'Connor, Hamm & Kirk, 2005; Wong, Fung, Chua, & McAlonan, 2008). Functional neuroimaging (fMRI) studies of people with autism have reported abnormal activation of the neural system subserving face processing, including the fusiform gyrus (Critchley et al., 2000; Dziobek, Bahnemann, Convit, & Heekeren, 2010; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Schultz, 2005), and amygdala (Baron-Cohen et al., 1999; Critchley et al., 2000; Schultz, 2005; Dziobek et al., 2010).

The face processing impairment in individuals with autism is explained by their dominant use of featural strategies for face processing (Rose et al., 2007). Evidence for this has been found in the reduced or absent face inversion effect in autism (e.g., Hobson, Ouston, & Lee, 1988b; Langdell, 1978; Rose et al., 2007; Teunisse & de Gelder, 2003). The so-called "face inversion effect" (FIE) (Yin, 1969) states that face recognition, perception and memorising of faces is more difficult when faces are inverted rather than presented in upright position, an effect not found in such a great measure for non-face objects. The face inversion effect is explained by adult expertise that mostly relies on configural properties of faces (Diamond & Carey, 1986). In typically developing individuals, recognition of facial stimuli has been argued to be based on the "holistic" processing of configurations of facial features rather than more feature-based strategies predominantly used for processing of other kinds of stimuli (Diamond & Carey, 1986; Eimer, 2000; Rose et al., 2007; Rossion & Gauthier, 2002). When faces are inverted, configuration of faces is disrupted, leading to recognising the configuration of faces as a marker of face specificity (Eimer, 2000; Marzi & Viggiano, 2011; Rose et al., 2007; Rossion, 2008, 2009). Although the atypical face inversion effect in autism

is considered an important characteristic of their impairment in facial processing, it cannot give a full explanation for the difficulties that individuals with autism have in processing facial stimuli. It is not clear whether differences in emotion processing and, particularly, impaired processing of facial emotional expressions in autism are perceptual in nature or also have a social origin. Behrmann, Thomas and Humprheys (2006) proposed that perceptual and social deficits are not mutually exclusive but can work in tandem. A recent fMRI study (Bookheimer, Wang, Scott, Sigman, & Dapretto, 2008) found that when children with autism were compared to typically developing children on the face inversion task, group differences could not be explained by dysfunctional activity of the fusiform face area (FFA) in the autistic group, but rather by brain areas implicated in social cognition, particularly the prefrontal cortex and amygdala. The authors suggested that the face inversion effect found in typically developing children is related more to the social significance of stimuli rather than visual information processing. Similarly, Grelotti, Gauthier and Schultz (2002) suggested that individuals with autism do not develop cortical face specialisation because of their reduced social interests. It has been proposed that there are critical periods in development of the fusiform face area, and autistic individuals miss these periods because of their reduced early social interest (Grelotti, et al., 2002; Pierce et al, 2001). They do not show difficulties in recognition of faces when faces are inverted because of their underdeveloped experience with faces and faces for them probably do not have the same social significance as for healthy subjects (Rose et al., 2007). This can be also related to the "amygdala theory of autism" (Baron-Cohen, et al., 1999), which implicates the amygdala in socio-emotion difficulties found in autism, based on findings of functional imaging that found less amygdala activation in autistic individuals compared to control subjects in various socio-emotional tasks, such as viewing facial emotional expressions (Critchley et al., 2000). Research on the amygdala with typically developing subjects have suggested that the amygdala is a robust detector of emotionally salient stimuli (i.e. faces) (e.g., Reinders, den Boer, & Büchel, 2005), and is involved in a preconscious and fast response to threat-related stimuli (Reinders et al., 2006).

Another perceptual area that has been extensively studied in autism is their preference for a local or piecemeal style of processing information. According to the weak central coherence theory (Happé & Frith, 2006), people with autism have difficulty in integrating details into the global whole to create meaningful information. This information does not need to be only perceptual, but also conceptual. It is suggested that impaired face processing in individuals with autism is a consequence of this strong reliance on local, piecemeal

information, because faces are visual stimuli that heavily rely on configural information. Predominantly focusing on local features of faces can impair the processing of the whole face. This would lead to attention being given to specific details of a facial expression, and then trying to connect details to recognise that particular expression (Tracy, Robins, Schriber, & Solomon, 2011). Although this detailed process for recognising emotion may lead to an accurate recognition of emotions, it may be ineffective when recognition of emotion needs to be automatic and rapid, such as in more naturalistic settings (Clark, Winkielman, & McIntosh, 2008).

A novel way of examining abnormal patterns found in autism is by studying healthy individuals with different levels of autistic traits. Baron-Cohen, Wheelwright, Skinner, Martin, and Clubley (2001) constructed the Autism-Spectrum Quotient (AQ) to measure the level of autism-like traits. This test is suitable for testing the recent conceptualisation of autism that suggests that autistic traits lie on a continuum and can be found to a greater or lesser degree in people. Individual differences in the level of autistic traits have been found to accurately predict performance on some tasks examining social cognition that are impaired in autism, such as inferring others' mental state from their eyes (Baron-Cohen at al., 2001). The face inversion effect was also examined in individuals with higher and lower scores on the autism quotient, and a smaller face inversion effect was found in individuals with higher AQ (Wyer, Martin, Pickup, & Macrae, 2012). Several studies have indicated local processing bias in individuals with higher autistic traits, similar to cognitive models of autism, such as weak central coherence (Happé & Frith, 2006) and the enhanced perceptual functioning (EPF) model (Mottron et al., 2006). For example, in a study that examined social cognition in individuals with high and low autistic traits with attentional cueing from gaze, differences between participants with high and low autistic traits were found in information processing style, with participants with high autistic traits showing a bias towards orienting to local details (Bayliss & Tipper 2005). This study applied the gaze-cueing procedure that consisted of presenting a face with the eyes moved to the left or right and subsequently presenting a target. Some faces always looked to the target (predictive-valid), some never looked to the target (predictive-invalid), and others looked toward the target location as many times as they looked away from the target location (nonpredictive). Although the standard gaze-cuing effects were not affected by these contingencies, the predictive-valid faces appeared more trustworthy for participants than the predictive-invalid faces. The significant negative correlation was found between this effect and scores on a scale assessing autistic-like traits. Differences between individuals with lower and higher autistic traits were also found on the

embedded figures test and adapted block design tasks, with superior performance by individuals with higher autistic traits on tasks in which local processing is advantageous (Grinter et al., 2009). Detailed visual processing as explained by weak central coherence was found in individuals with high autistic traits by using non-linear visual evoked potentials, where it was shown that detailed local processing in high AQ scorers was caused by a delay in magnocellular processing in the occipital cortex (Sutherland & Crewther, 2010). Magnocellular delay leads to disruption in "magnocellular advantage" (Laycock, Crewther, & Crewther, 2007), and perception without magnocellular advantage does not benefit from "global analysis and grouping that normally occurs courtesy of the dorsal stream – hence leading to weak central coherence" (Sutherland & Crewther, 2010, p. 2096).

Although there are an increasing number of studies that examine various cognitive and perceptual characteristics in healthy people with different levels of autistic traits, not enough studies used neuroimaging methods. The current study will try to extend knowledge relating to the processing of facial emotional expressions in upright and inverted faces in subjects with different levels of autistic traits, using Electroencephalogrphy (EEG).

The temporal dynamics of face processing have usually been examined by the technique of event-related potentials (ERP) because of their high inherent temporal resolution. There are several important face-specific ERP components, with the majority of face studies focusing on early components, predominantly P100 and N170. The occipital P100 is an early visual component generated by extrastriate visual areas (Di Russo, Martínez, Sereno, Pitzalis, & Hillyard, 2001). This positive ERP component occurs approximately 100 ms after stimulus presentation (e.g., Itier & Taylor, 2002; Linkenkaer-Hansen et al., 1998; Taylor, 2002) and has been found to be shorter and sometimes smaller for upright faces compared to inverted faces (e.g., Itier & Taylor, 2002; Itier & Taylor, 2004a; Linkenkaer-Hansen et al., 1998). The P100 amplitude has been found to be modified by facial expressions. For example, several studies showed that this component was larger for angry and fearful faces than neutral faces, suggesting that it represents enhanced sensory processing of threatening expressions (Batty, & Taylor, 2003; Pizzagalli, Regard, & Lehmann, 1999).

The N170 component is considered a neurophysiological correlate of face perception as it is often larger and faster in the recognition of faces than non-face objects (e.g. Bentin, Allison, Puce, Perez, & McCarthy, 1996; Itier & Taylor, 2004a). It usually occurs at occipitotemporal sites at about 170 ms post-stimulus, with neural generators considered to be in the fusiform gyrus (e.g., Puce, Allison, & McCarthy, 1999; Shibata et al., 2002) and superior temporal sulcus (Itier & Taylor, 2004c). Intracranial recordings found sources for the

N200 (N170) in the fusiform gyrus/inferior temporal gyrus as well as on the lateral occipitotemporal cortex (Allison et al., 1999; Puce et al., 1999). The N170 is proposed to reflect structural encoding of facial features, and is usually delayed and larger for inverted than upright faces (Bentin et al., 1996; de Haan, Pascalis, & Johnson, 2002; Eimer, 2000; Itier & Taylor, 2002, 2004a; Linkenkaer-Hansen et al., 1998; Rossion et al., 2000; Sagiv & Bentin, 2001). However, it is not yet clear whether the N170 component is affected by facial expressions. Some ERP studies did not find modulation of the N170 by facial emotional expressions (Ashley, Vuilleumier & Swick, 2004; Balconi & Lucchiari, 2005; Eimer & Holmes, 2002; Eimer, Holmes, & McGlone, 2003), supporting the hypothesis that the structural encoding and processing of emotional facial expressions are independent processes. This hypothesis is in line with the models of face processing proposed by Bruce and Young (1986) and by Haxby, Hoffman, and Gobbini (2000) that consider the structural encoding of faces and processing of facial emotional expressions as independent and parallel processes. However, some recent studies have supported modulation of this face-specific component by facial expressions (e.g., Batty & Taylor, 2003; Blau, Maurer, Tottenham, & McCandliss, 2007; Stekelenburg & de Gelder, 2004).

ERP modulations sensitive to the emotional significance of stimuli are often observed at later latencies. The P200 is the component that peaks at around 150-200 ms after stimulus onset. This component has been found to be sensitive to face configuration (Thatcherization: Boutsen, Humphreys, Praamstra, & Warbrick, 2006; elongation: Halit, de Haan, & Johnson, 2000). In studies with emotional faces presented in upright and inverted orientation, the P200 was found to be delayed for inverted faces compared to upright ones, suggesting that this component represents structural encoding of facial expressions (Eimer & Holmes, 2002; Ashley et al., 2004). Another component implicated in emotional and social processing is the Late positive potential (LPP), an ERP component that peaks around 300 ms. Although some studies have found larger LPP during the processing of negative faces (e.g., Schupp et al., 2004), supporting the "negativity bias hypothesis", this component has also been found to be enhanced by emotional compared to neutral faces (Eimer & Holmes, 2002), suggesting that the LPP is modulated by the most arousing or motivationally significant stimuli (Eimer, Holmes, & McGlone, 2003).

ERP studies in children and adults with autism have found abnormal neural responses to faces compared to typically developing controls (e.g., Dawson et al., 2002; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Webb, Dawson, Bernier, & Panagiotides, 2006). Together with N170, the P100 is the most investigated ERP component in face

processing in autism. Previous studies on facial processing in ASD did not find larger P100 amplitude for inverted faces than upright faces in children with autism in comparison to children with typical development (Hileman, Henderson, Mundy, Newell, & Jaime, 2011). It is also examined emotional processing in autism. For example, O'Connor et al., (2005) did not find differences between adults with ASD and healthy controls on P100 amplitude, but showed a delayed P100 latency for facial expression in adults with autism compared to adults with typical development. However, this difference in latency was not found between children with Asperger Syndrome and typically developing children. In another study, O'Connor, Hamm, and Kirk (2007), did not find any differences between adults with and without Asperger Syndrome on P100 latency or amplitude. However, Wong et al., (2008) found a delayed early visual component for children with autism in comparison with the control group, suggesting that children with autism are slower in automatic low-level visual processing of emotional stimuli. Differences between autistic and typically developing participants were also found on the N170 component. For example, absent or reduced sensitivity to face inversion and delayed latency in the N170 component was found in autistic compared to typically developing subjects (e.g., Dawson et al., 2002; Dawson et al., 2005; McPartland et al., 2004; O'Connor et al., 2005, 2007; Webb et al., 2006). It was also suggested that individuals with autism show smaller N170 amplitudes to facial expressions compared to neurotypical individuals (O'Connor et al., 2005). However, O'Connor et al., (2005) did not find significant effects of facial emotional expression on N170 amplitude or latency in groups of children and adults with Asperger's syndrome and typically developing controls, consistent with previous studies that did not find modulation of the N170 by facial emotional expressions. These authors explain their results by the possibility that neutral faces may be interpreted as emotional as well, because of their social importance.

Altogether, a common finding of previous research is an atypical activation of early face-related ERPs in autism. The present study will try to expand this knowledge by examining modulation in early and later ERPs by facial emotional expressions to see if difficulties observed in subjects with autism can also be seen in healthy individuals with high autistic traits.

6.2. Aims and hypothesis

The goal of the current work is twofold. Its first goal is to examine modulation of early and late ERP components by facial expressions, and to examine if face inversion

influences this modulation, regardless of the autistic tendency of participants. A second goal is to examine whether the degree of autistic tendency modulates the cortical processing of emotional faces.

The main hypothesis of this study relates to the processing of upright and inverted faces, and states that an absent or reduced face inversion effect in the High AQ group will also be found for face-specific components, particularly the N170 ERP component.

As research on emotion processing in individuals with different levels of autistic traits is scarce, our analysis of group differences will be mostly exploratory. Also, as there are few studies on emotion processing in inverted faces, and as the results about processing of various emotional expressions in inverted faces are mixed, it is difficult to make certain predictions. However, based on a previous study of emotion processing of inverted faces, it can be predicted that emotion differentiation found for upright faces suggests that those emotion effects occur because of emotional effects per se, whereas if those effects also occur for inverted faces, it would suggest that it is a consequence of configural/physical aspects of a particular facial expression (Eimer & Holmes, 2002; Ashley et al., 2004).

6.3. MATERIALS AND METHODS

6.3.1. Participants

Thirty-eight participants (20 Females, all right-handed) completed an online version of the AQ (Baron-Cohen et al., 2001) and EQ scales (Baron-Cohen & Wheelwright, 2004), and participated in the EEG study **(Table 6-1)**. Demographic information of participants was also collected online. During data analysis, one participant was excluded due to excessive artefacts. All participants had normal or corrected-to-normal vision, with no neurological impairment. All participants signed informed consent to participate and the experimental procedures were approved by the ethics committee of the Swinburne University of Technology, Melbourne, Australia.

6.3.2. Measures

All participants completed online questionnaires, including the Autism Quotient (AQ) and the Empathy Quotient (EQ) questionnaires. They also completed the Advanced Ravens Progressive Matrices, before or after EEG testing.

Table 6-1. Participant characteristics

Participants

AQ		AQ score	EQ score	Raven's	Age
Low (n = 13, 6 F)	Mean	8.69	54.23	20.69	28.54
	Std. Deviation	2.175	10.264	4.590	3.843
	Minimum	4	41	12	21
	Maximum	11	70	31	35
Mid (n = 13, 8 F)	Mean	14.85	49.15	24.08	28.31
	Std. Deviation	2.410	9.590	4.231	6.447
	Minimum	12	27	17	18
	Maximum	19	64	30	38
High (n = 12, 6 F)	Mean	25.25	34.25	22.42	29.00
	Std. Deviation	5.242	10.635	6.417	9.620
	Minimum	20	10	12	19
	Maximum	39	54	31	55

The Autism-Spectrum Quotient (AQ) is a self-administered questionnaire developed by Baron-Cohen et al. (2001) that consists of 50 questions, devised to quantitatively measure the degree to which a person with normal intelligence has autistic traits (Baron-Cohen et al., 2001; Woodbury-Smith et al., 2005). It is made up of 10 questions assessing each of five different areas: social skill, attention switching, attention to detail, communication and imagination. Participants respond using a 4-point rating scale, from "definitely agree" to "definitely disagree".

The Empathy Quotient (EQ) is a self-administered questionnaire that consists of 40 questions assessing empathy (Baron-Cohen & Wheelwright, 2004).

Adults with autism scored significantly lower on the EQ than did neurotypical controls, and the EQ was found to be inversely correlated with the AQ (Baron-Cohen & Wheelwright, 2004). In the neurotypical group, sex differences in the EQ were found with higher scores for women than men (Baron-Cohen & Wheelwright, 2004; Lawrence et al., 2004). However, the questionnaire mostly measures "an individual's beliefs about their own empathy or how they might like to be seen or think about themselves" (Baron-Cohen & Wheelwright, 2004: p. 171). The EQ was found to have high test-retest reliability (Lawrence et al., 2004). A recent study (Sucksmith et al., 2013) found deficits on the EQ in fathers of a child with autism, suggesting that this questionnaire is important for research into the broad autism phenotype.

The Raven's Advanced Progressive Matrices is a standardised intelligence test measuring mostly the nonverbal domain. It consists of visually presented geometric figures where one part is missing and the missing part must be selected from a panel of suggested answers to complete the designs (Raven, 2000; Kunda, McGreggor, & Goel, 2009). Because of its high correlation with other multidomain intelligence tests, this test has an important place within psychometric testing as a test of general cognitive ability and intelligence. It was developed to measure two components of general cognitive ability – educative and replicative ability (Ravens, 2000). Educative ability refers to the ability to extract schematic information from a complex situation, and replicative ability to absorb, recall and reproduce information. One positive aspect of this test is its easiness of administration and interpretation (Raven, 2000). In the current study, we used the Raven's test with a time limit of 20 minutes.

6.3.3. Face and house stimuli

Stimuli consisted of greyscale photographs of the faces of 6 male and 6 female models, with both open and closed mouth examples, and 15 different houses. Models' faces depicted neutral, fearful, happy, and sad expressions and were cropped to remove external features. The images of the faces were taken from the NimStim set (Tottenham et al., 2009), and the images of houses were the same stimuli as used in Reinders et al., (2005, 2006).

6.3.4. Procedure

The subjects sat in an electrically shielded, dimly-lit and sound-attenuated room in front of a computer screen. The experiment was programmed with E-Prime 1.2 (Psychology Software Tools, Inc., Pittsburgh, PA). Stimuli were presented in 8 blocks of 138 trials. Block order was counterbalanced across participants. The order of trials within each block was randomised. Before the experimental procedure began, participants were given practice. At the start of the experiment, a white fixation cross appeared in the middle of the screen and lasted for 1500 ms. Shortly thereafter, a picture of a face or house stimuli was displayed for the duration of 750 ms, followed by second picture of a face or house for the same duration (**Figure 6-1**). Participants performed a one-back task in which they were required to press a button as soon as they recognised that the two sequentially presented stimuli were the same. Identical faces had the same orientation, identity and emotional expression, and identical houses also had the same orientation. There were around twenty percent of such repetitions in each block. Left and right hands were counterbalanced among participants. This procedure is

considered to assign similar task relevance to faces as to non-face stimuli (houses), as well as different emotional expressions.

Figure 6-1. Experimental procedure
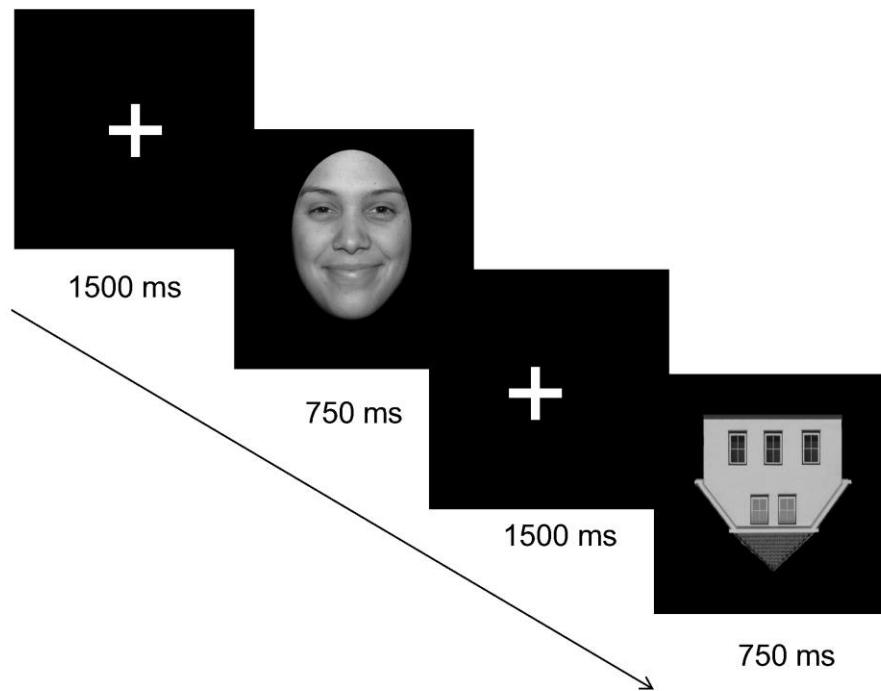
6.3.5. ERP recording and analysis

EEG activity was recorded using a Geodesic Sensor Net (EGI) with 64 electrodes, with the vertex (Cz) electrode used as a reference. The amplification was set at 1000 times. EEG signals were filtered through a 0.05 Hz high-pass filter and 70 Hz low-pass filter with a sampling rate of 500 Hz. Electrode impedances were kept below 5 kΩ. Recordings were re-referenced to the average reference as computed from all scalp electrodes (for components: P100 and N170), and to the average of mastoids (for P200 and LPP).

EOG was recorded from two electrodes placed at the external canthi of both eyes and from two electrodes on the infra-orbital and supraorbital areas of the left eye to monitor for eye movements and blinks. EOG blink artefacts were corrected using a regression-based algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986), supplied as part of the SCAN software. The raw data were segmented into epochs using a window of 100 ms pre-stimulus to 800 ms post-stimulus. After baseline correction, trials in which amplitude exceeded ±80

μV were automatically rejected, which eliminated eye blinks and other movements. In addition, all epochs were visually inspected and epochs containing eye movements and other artefacts were removed. Only epochs containing at least 50 trials were taken for further analysis. Bad channels were corrected by individual channel-interpolation (interpolating channel by using nearby channel data). ERPs were averaged separately for each stimulus category (for faces each emotion was averaged in upright and inverted orientation and houses in upright and inverted) and low-pass filtered at 30 Hz (6dB/octave).

6.3.6. ERP analyses

The time windows for ERP components were selected based on a review of the literature and examination of grand averages. The N170 ERP was examined at the lateral occipito-temporal site (P7 and P8), the P100 at the occipital site (O1 and O2), P200 and LPP components at the frontal, central and parietal sites with lateral electrodes (F3, F4, C3, C4, P3, P4). The peak amplitudes and latencies were measured in the following latency windows: 80 - 160 ms (P100), 140 - 220 ms (N170), 100 - 250 ms (P200), and 400 – 800 ms (LPP). ERP amplitude and latency were analysed with repeated-measures ANOVA using AQ Group as the between-subject factor, and emotion (neutral, happy, fearful, sad), orientation (upright, inverted) and hemisphere (left, right for N170, P100)/electrode (three for P200 and LPP; electrodes varied according to the components studied) as within-subject factors. To further investigate face and house processing, a repeated-measures ANOVA was conducted separately, with stimulus category (neutral face and house), orientation and hemisphere as within-subject factors (only for early visual components, P100 and N170). Similarly, the stimulus-inversion effect (as upright/inverted) was calculated for faces and houses separately.

Degrees of freedom were adjusted with the Huynh-Feldt epsilon for factors with more than two levels. Pairwise comparisons t-test, one-way ANOVA and Pearson correlations were performed to supplement ERP findings. The Bonferroni adjustment was applied to correct for multiple comparisons ($p < 0.05$).

6.4. RESULTS

6.4.1. Behavioural

Behavioural data showed significantly reduced accuracy for inverted compared to upright faces across all subjects: upright was 82% and inverted 68% (significant orientation

effect) (F(1,35) = 48.53, p = 0.001). There were not significant differences in accuracy rates for various facial expressions

No group differences were found in accuracy rates. Further planned comparisons for each group revealed that all of them showed significantly reduced accuracy rates for inverted faces (High AQ – upright: 83%, inverted: 69%, F(1,11) = 15.19, p = 0.002); Low – upright: 83%, inverted: 68%, F(1,12) = 23.52, p = 0.001); Mid AQ – upright: 80%, inverted: 67%, F(1,12) = 11.99, p = 0.01) (**Figure 6-2**). Significant differences in recognising inverted facial expressions were found only in the Low AQ group (F(3,36) = 3.06, p = 0.04).

Across all subjects, response times (RTs) were faster for upright than inverted faces (F(1,35) = 6.42, p = 0.02) (upright: 536.750 ms; inverted: 552.741 ms), with no RTs difference for upright and inverted houses (p = 0.42). In upright orientation, the emotion effect was significant (F(3,96) = 7.21, p = 0.001), with longer recognition rates for happy compared with other facial expressions (all comparisons, p < 0.03). No groups showed significant RTs differences for upright and inverted faces.
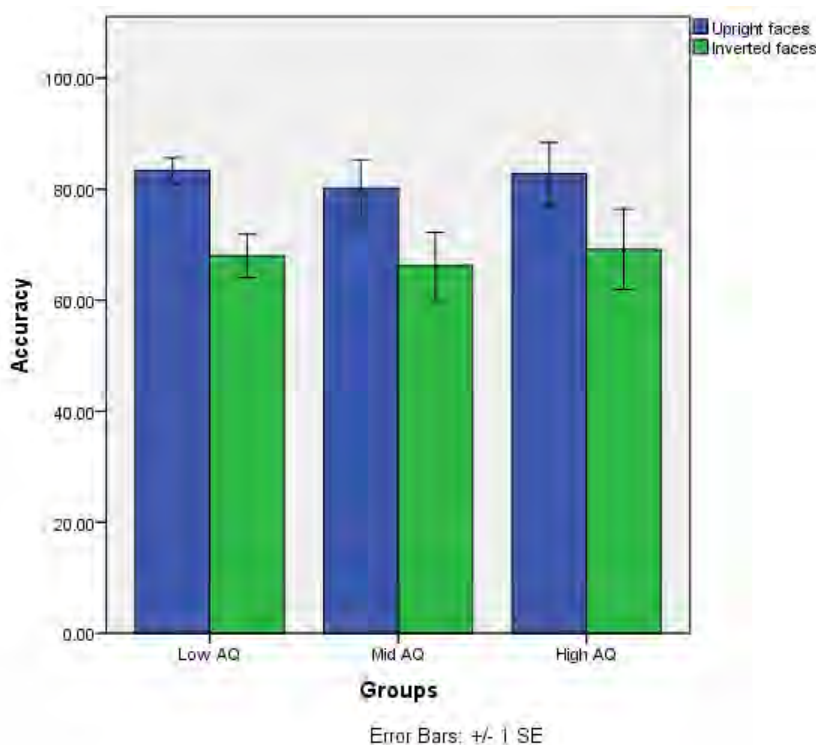
Figure 6-2. Accuracy rates for upright and inverted faces. All groups showed reduced accuracy rates for inverted faces.

The one-way ANOVA was used to compare EQ scores between different groups (**Figure 6-3**), and the analysis revealed significant group differences (F = 12.91, p = 0.001), with the High AQ group showing lower scores compared to the Low AQ (p = 0.0, mean difference = 19.98) and Mid AQ groups (p = 0.0012, mean difference = 14.9). Previous

studies with EQ showed empathy difficulties in individuals with autism (Baron-Cohen & Wheelwright, 2004) and in parents of children with autism, particularly fathers (Sucksmith, Roth, & Hoekstra, 2013). Sucksmith et al., (2013) suggested that lower scores on self-report empathy tests may represent reliable features of the broad autism phenotype in fathers.

No significant group differences were found for Raven's matrices.
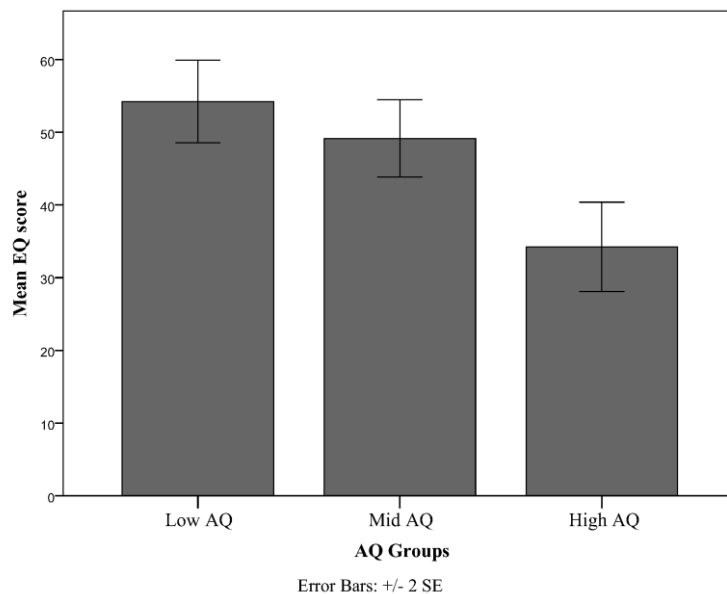
Figure 6-3: Mean EQ scores by AQ group. High AQ group had lower EQ scores when compared to Low and Mid AQ groups.

6.4.2. ERP Results

ERP results are divided into results across all groups (for all participants) and also results related to group comparisons. Firstly, neutral faces are compared with houses, including showing results of inversion effect for both stimuli categories. The comparison between neutral faces and houses was performed only for P100 and N170 components. Subsequently, results comparing upright vs. inverted faces (examining inversion effect across all facial expressions) and emotion discrimination for both upright and inverted faces are presented. Only significant effects are reported for each of ERP components. Examples of ERP waveforms (P100 and N170) for upright and inverted faces and houses can be seen in **Figures 6-4 − 6.7**.

6.4.2.1. Across all groups

6.4.2.1.1. Neutral faces vs. houses

P100

A comparison between neutral faces and houses revealed the main effect of stimulus category for both P100 amplitudes ($F(1,35) = 39.83$, $p = 0.001$) and latencies ($F(1,35) = 15.52$, $p = 0.001$). Across all AQ groups and hemispheres, neutral faces elicited larger P100 amplitudes compared with houses in both upright ($F(1,35) = 8.74$, $p = 0.01$) and inverted ($F = 38.89$, $p = 0.001$) orientation (**Figure 6-4**), and shorter latencies for houses compared with faces were found in both upright ($F = 7.88$, $p = 0.01$) and inverted ($F = 19.19$, $p = 0.001$) orientation.

A significant stimuli x orientation interaction ($F(1,35) = 4.13$, $p = 0.05$) was also found for P100 amplitudes. Further analysis revealed that, whereas across both hemispheres neutral faces exhibited marginally larger P100 amplitudes for inverted than upright faces ($F = 3.69$, $p = 0.06$), there was not a significant effectof orientation for houses ($F = 1.15$, $p = 0.29$). However, an orientation x hemisphere interaction was found for houses across both hemispheres ($F = 11.3$, $p = 0.02$), showing significant orientation effect for houses in the right hemisphere only ($F = 5.76$, $p = 0.02$) with larger amplitudes in upright than inverted orientatin. (**Figures 6-5** shows grand average ERP waveforms of P100 amplitude for orientation effect for neutral faces and houses in each hemisphere.) In addition, analysis also showed a significant hemisphere effect ($F(1,35) = 8.31$, $p = 0.01$) found only for neutral faces, with larger amplitudes in the right hemisphere.

Further analysis of P100 latencies showed a significant effect of orientation for neutral faces only ($F(1,35) = 10.32$, $p = 0.003$), with shorter latencies in upright than inverted orientation. The paired samples t-test showed that thise effect was significant only in the left hemisphere ($p = 0.01$).

Figure 6-4. **Grand average ERP waveforms of P100 amplitude in response to neutral faces and houses.** Electrode site O1 and O2 are displayed comparing neutral faces and houses in upright and inverted orientation (across all participants). Figures show larger P100 amplitudes and longer P100 latencies for neutral faces.
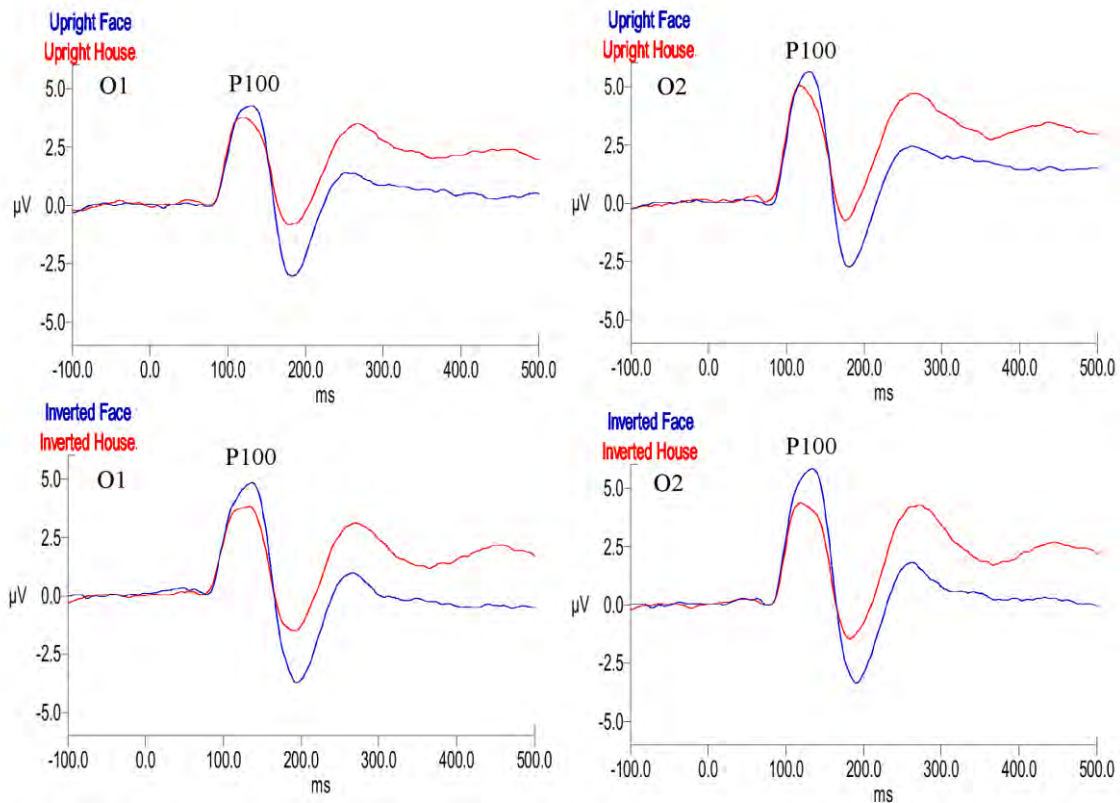
Figure 6-5. Grand average ERP waveforms of P100 amplitude in response to upright and inverted neutral faces and houses. Electrode site O1 and O2 are displayed showing a tendency for larger P100 amplitudes for inverted compared to upright faces, but larger P100 amplitudes for upright compared to inverted houses at O2.
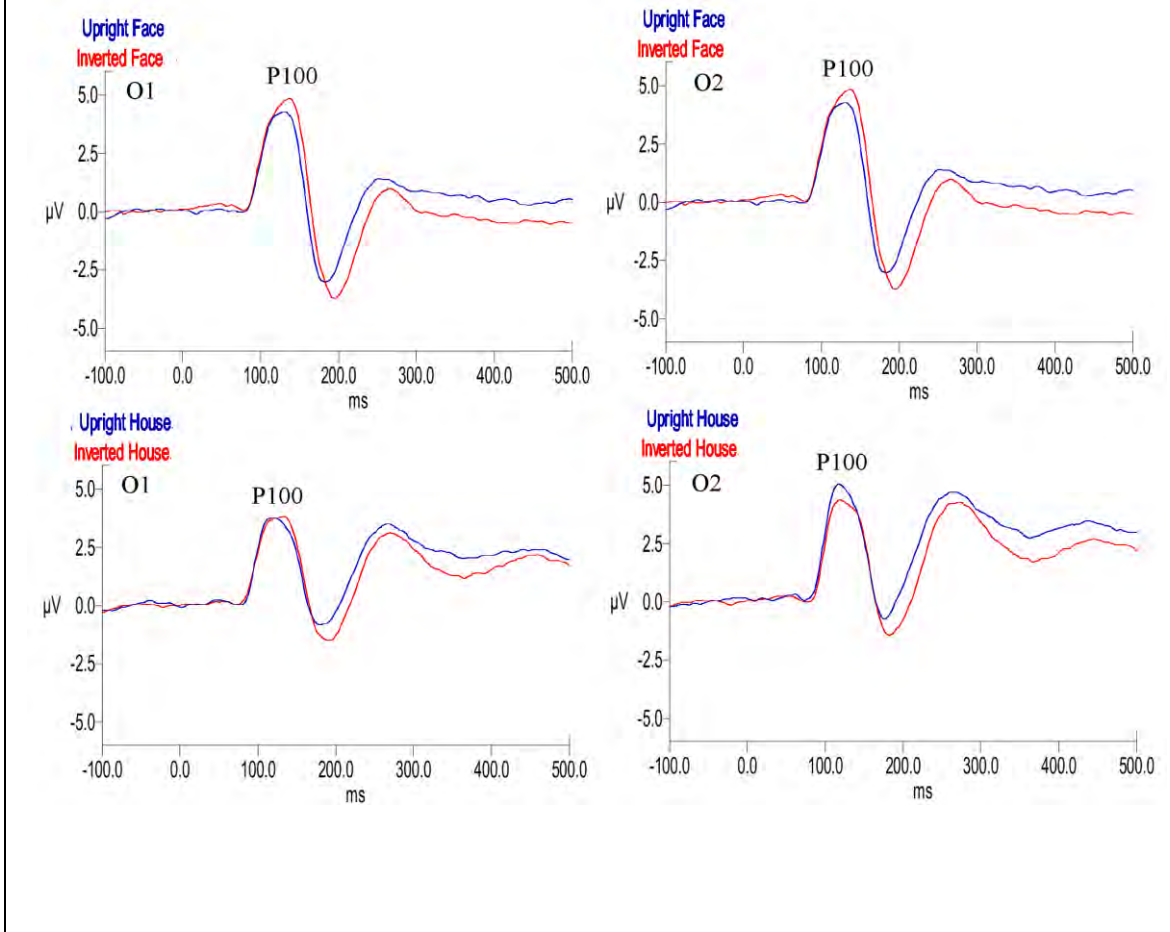
N170

Analysis of N170 amplitudes across neutral faces and houses revealed a main effect of stimulus category, with larger amplitudes for faces than houses (upright: $F_{(1,35)} = 63.3$, p = 0.001; inverted: F = 74.83, p = 0.001), and shorter latencies for houses compared to faces in inverted orientation (F(13.97, p = 0.001), with no significant effect for upright stimuli (p = 0.84) (**Figure 6-6**). No group differences were found.

Analysis across all groups revealed larger amplitudes for inverted than upright houses ($F_{(1,35)} = 9.13$, p = 0.01), with the orientation effect qualified by orientation x hemisphere interaction ($F_{(1,35)} = 4.03$, p = 0.05), indicating a significant effect of orientation in the right

hemisphere (p = 0.001) only (in the left hemisphere, p = 0.14) (**Figure 6-7**). Analysis for neutral faces showed significant inversion effect (F(1,35) = 22.4, p = 0.0001) bilaterally (**Figure 6-7**). The topographic maps of upright and inverted neutral faces and houses is displayed in **Figure 6-8**.

Fig. 6-6. Grand average ERP waveforms of N170 amplitude in response to neutral faces and houses. Electrode site P7 and P8 are displayed comparing neutral faces and houses in upright and inverted orientation (across all participants). Larger N170 amplitudes were found for neutral faces compared to houses in both orientations, and also longer N170 latencies for neutral faces compared to houses were found in inverted orientation.
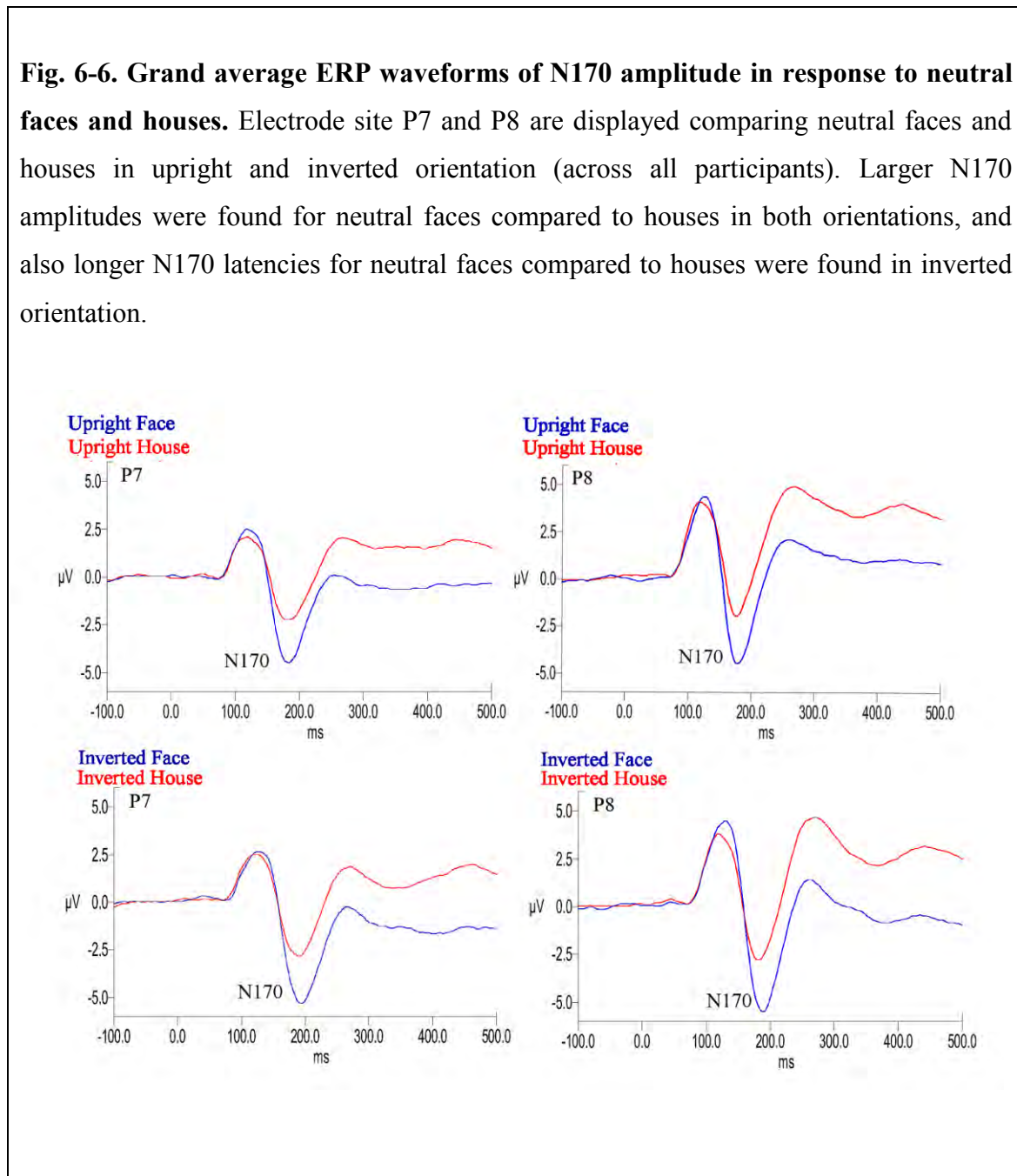
Figures 6-7. Grand average ERP waveforms of N170 amplitude in response to upright and inverted neutral faces and houses (across all participants). Electrode site P7 and P8 are displayed showing orientation effect for neutral faces and houses across all participants. A significant main effect of orientation was found for neutral faces in both hemispheres, with larger amplitudes for inverted faces. Although a main effect of orientation was also significant for houses bilaterally, an analysis for each hemisphere showed that this effect was significant only in the right hemishere. Both stimulus categories showed shorter N170 latencies for upright than inverted stimuli, although this effect for houses was found to be significant only in the left hemisphere (at P7) (and also bilaterally).
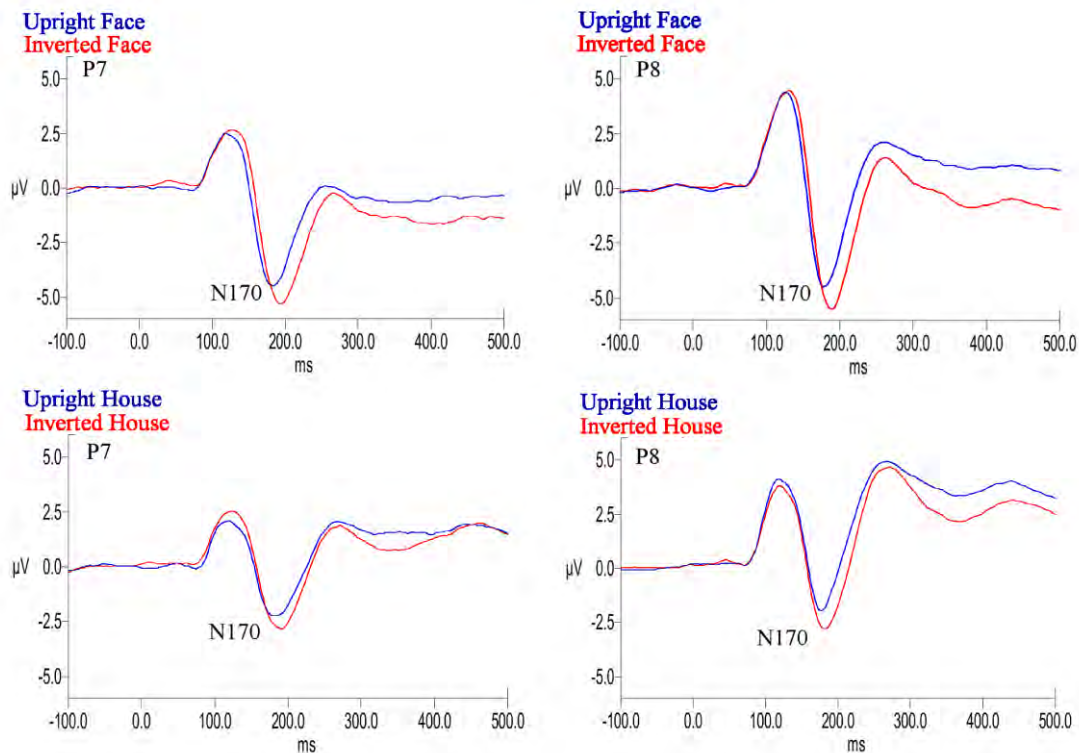
Figure 6-8. Topographic maps for upright and inverted neutral faces and houses at the latency of maximum N170 amplitude (140-220 ms). Weaker activity is seen for upright and inverted houses than for neutral faces (A.). The topographic maps show the inversion effects (inverted minus upright) for neutral faces and houses, respectively (B.). Note absent negativity (blue colour) at posterior lateral sites for houses.
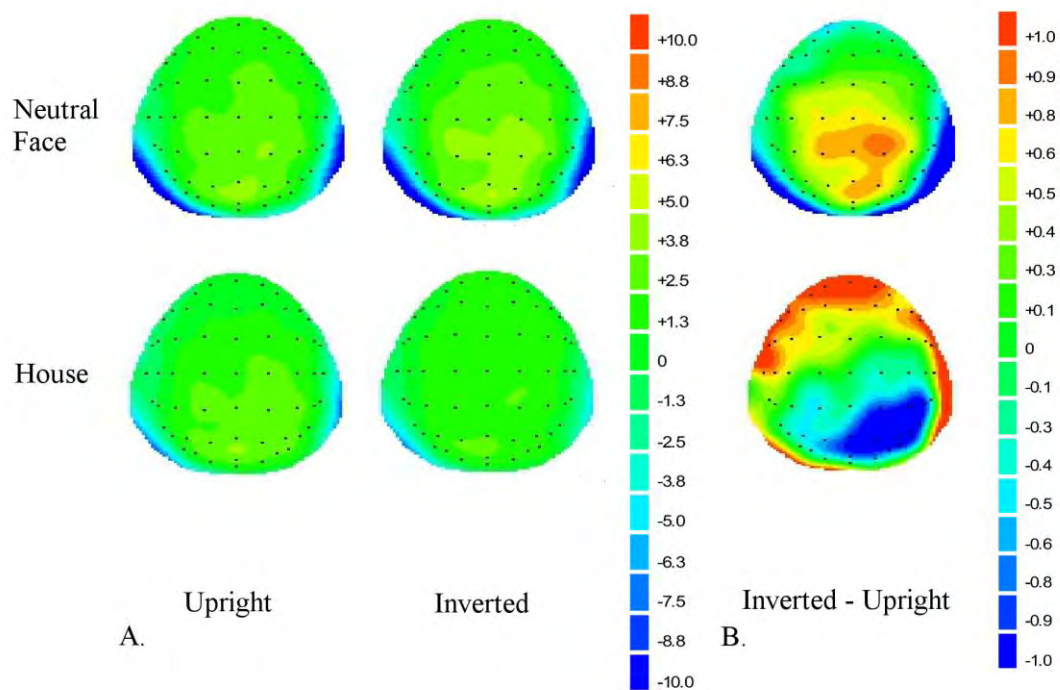
6.4.2.1.2. Upright vs. inverted faces

P100

Analysis of the P100 amplitude did not reveal a significant effect of orientation ($F_{(1,35)} = 1.838$, $p = 0.184$) for face stimuli across all AQ groups and hemispheres. However, the analysis of the P100 latency for facial expressions revealed shorter P100 latencies for upright than for inverted faces ($F_{(1,35)} = 21.69$, $p = 0.0001$) (126.64 ms and 130.122 ms for upright and inverted, respectively).

N170

Across all AQ groups, the N170 amplitude revealed a significant effect of orientation for the face stimuli ($F_{(1,35)} = 20.38$, $p = 0.001$), indicating that inverted faces elicited larger

N170s (-6.189 µV) than did upright faces (-5.402 µV) (**Figure 6-9**). This effect was significant in both hemispheres. This finding is in agreement with previous ERP studies on face processing (Rossion et al., 1999) that showed enlarged N170s amplitude for inverted faces. Results also showed shorter N170 latencies for upright faces than for inverted faces $(F(1,35) = 117.36, p = 0.001; 183$ ms and 191 ms for upright and inverted faces, respectively).

P200

Analysis of P200 amplitudes across all groups revealed a main effect of orientation at frontal $(F(1,35) = 13.8, p = 0.01)$ and central $(F = 27.82, p = 0.001)$ sites, with larger amplitudes for inverted than upright faces (**Figure 6-9**).

The significant effect of orientation was also found for latencies at the frontal site $(F = 15.06, p = 0.001)$ across all groups. At central and parietal sites, no orientation effect was found, but an interaction of orientation and group was identified.

LPP

Analysis of LPP amplitudes revealed a main effect of orientation at frontal $(F(1,35) = 5.53, p = 0.02)$ and central $(F = 4.99, p = 0.03)$ sites, with larger amplitudes for inverted than upright faces (**Figure 6-9; 6-10**). Nothing significant was found at the parietal site.

Figure 6-9. Grand average ERP waveforms of the N170, P200 and LPP components in response to upright and inverted faces (page 141). Vertical scale represents voltage amplitude in uV and horizontal scale displays latency in ms.

Figure 6-9.
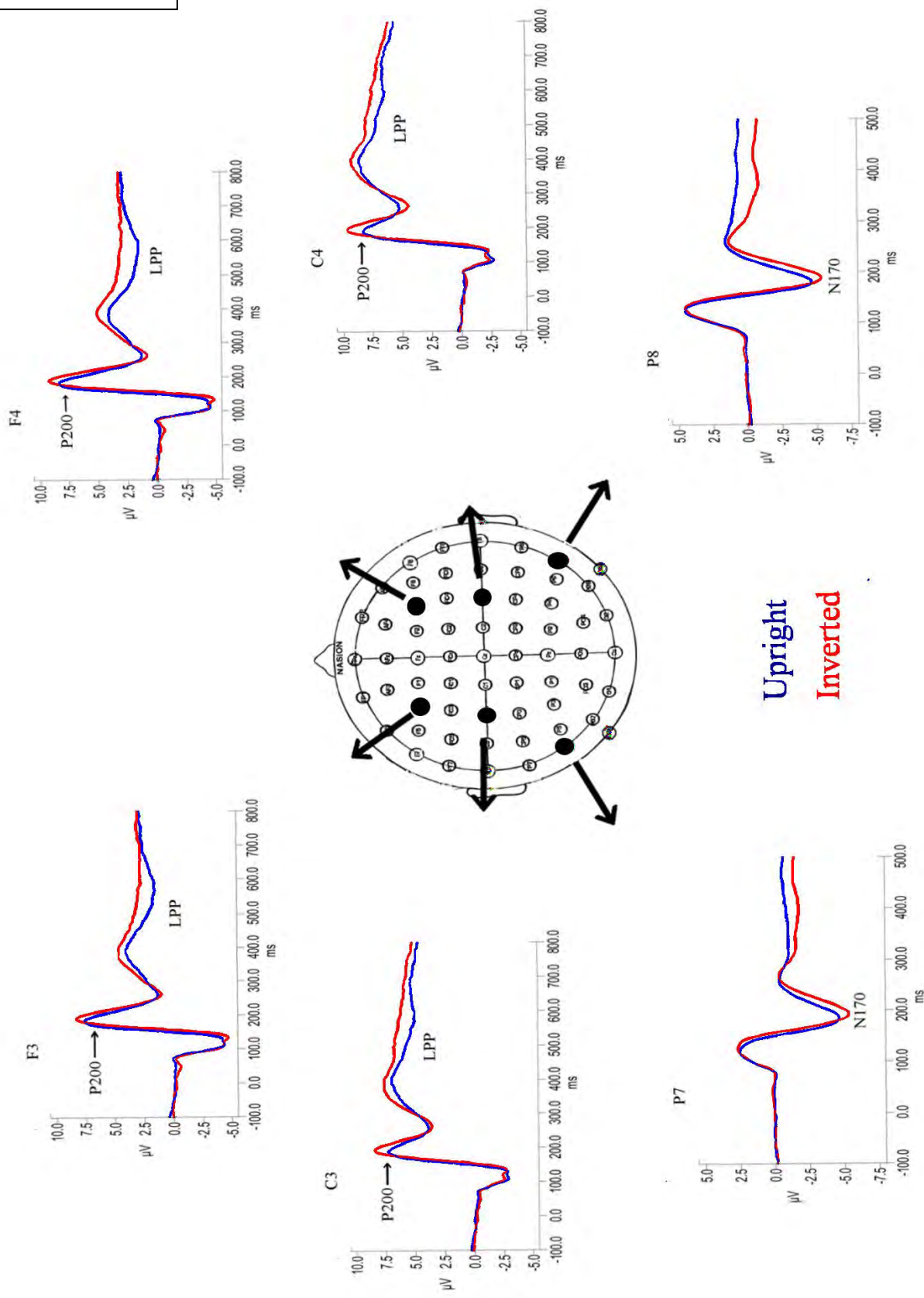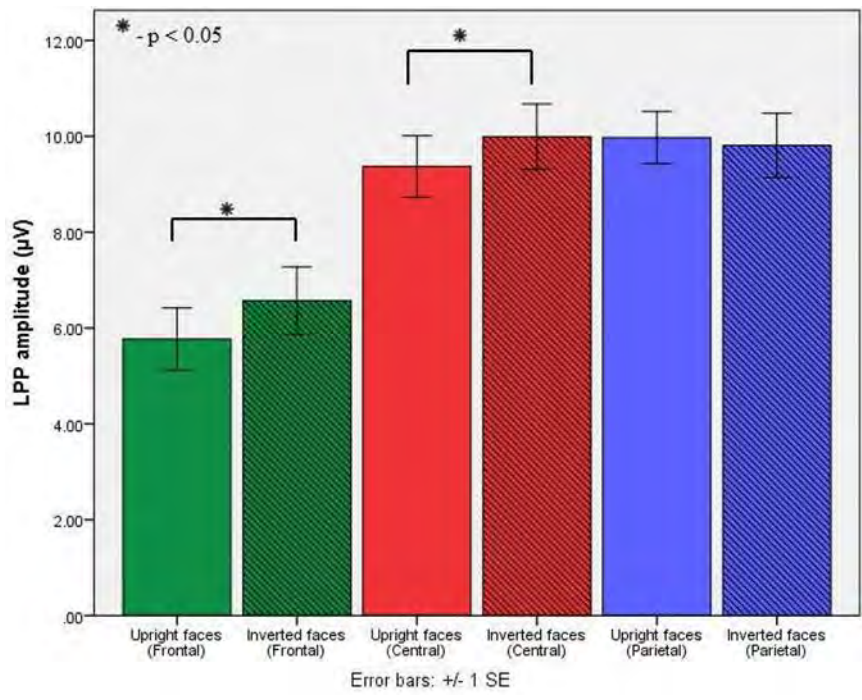
Figure 6-10. LPP amplitude in response to upright and inverted faces (bilaterally).

6.4.2.1.3. Emotion differentiation

P100

The analysis of P100 amplitude for upright faces returned a significant main effect of emotion ($F(3, 97) = 2.79$, $p = 0.05$) across all groups and both hemispheres, indicating marginally larger P100 amplitudes to fearful compared to happy faces ($p = 0.07$).

Concerning latencies for upright faces, analysis revealed a main effect of emotion ($F(3,95) = 3.86$, $p = 0.02$), and post-hoc tests showed a tendency for longer latencies for sad faces compared with other facial expressions, but significant differences were found only between sad and happy faces ($p = 0.03$).

No emotion effect was found for inverted faces ($F(3,108) = 0.82$, $p = 0.49$ and $F(3,97) = 0.03$, $p = 0.99$, for amplitude and latency, respectively).

N170

Analysis of the N170 amplitude for upright facial expressions across all groups revealed a significant effect of emotion ($F(3,105) = 2.73$, $p = 0.05$) bilaterally (**Figure 6-11**), with a larger amplitude for happy than neutral faces ($p = 0.04$) (larger N170 amplitudes for fearful than neutral faces were found only when not adjusted for multiple comparisons (LSD),

with p = 0.03) However, analysis for each hemisphere showed significant emotion effect only in the left hemisphere (F = 2.87, p = 0.04), with marginally larger fearful compared to neutral faces (p = 0.06).

Analysis of the N170 latency for upright facial stimuli across all groups revealed a marginal effect of emotion x hemisphere interaction ($F(3,105) = 2.57$, $p = 0.07$). Further analysis revealed a significant emotion effect in the left hemisphere ($F(3,105) = 4.078$, $p = 0.01$), indicating shorter latency for neutral compared to happy ($p = 0.01$) and marginally sad ($p = 0.07$) faces. No group differences were found.

The High AQ group showed a tendency to have lower amplitudes for all facial expressions compared to the Low AQ group, although no statistically significant group differences were found.
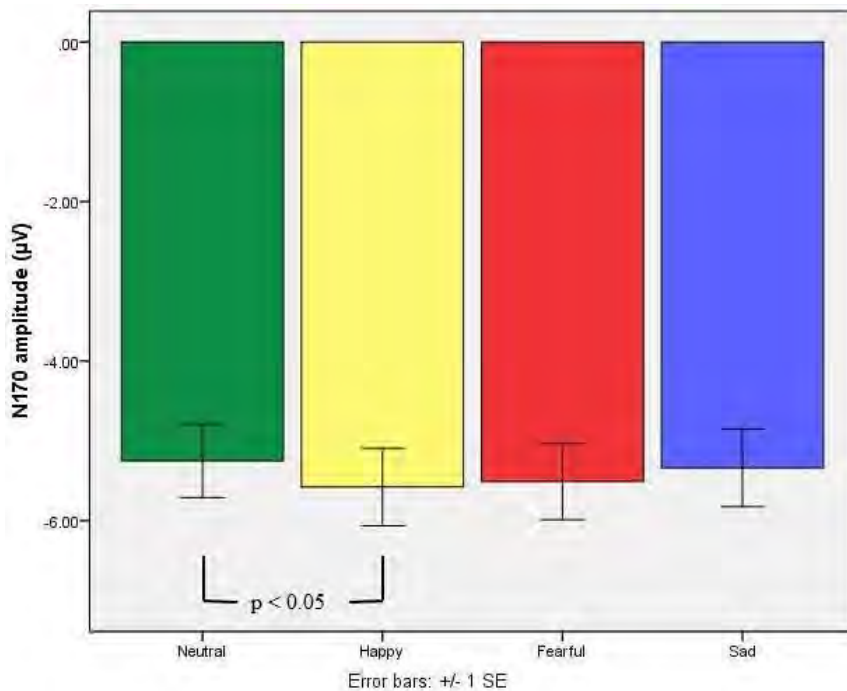
Figure 6-11.
N170 amplitude for upright faces (bilaterally). Significant difference was found between happy and neutral faces.

P200

At the central site, across all groups and both hemispheres in *upright* orientation, a main effect of emotion was found ($F(3,105) = 3.92$, $p = 0.01$), indicating marginally larger amplitudes for happy compared to neutral faces ($p = 0.06$).

LPP

Across all groups and both hemisphere, a main effect of emotion for upright faces was found only at the central site ($F(3,105) = 4.86$, $p = 0.003$), with larger amplitude to fearful

than neutral faces (p = 0.02) and also marginally larger amplitude to happy than neutral faces (p = 0.06) (**Figure 6-12**). This effect of emotion at the central site was significant in both hemispheres (left, p = 0.04; right, p = 0.01), showing larger LPP amplitudes to happy and fearful compared to neutral faces in the left hemisphere (both p = 0.05), and larger amplitudes to fearful than neutral faces (p = 0.01) in the right hemisphere. No significant group differences were found. A main effect of hemisphere was also found for upright faces at this site (F(1,35) = 18.52, p = 0.001), with larger amplitudes in the right hemisphere.
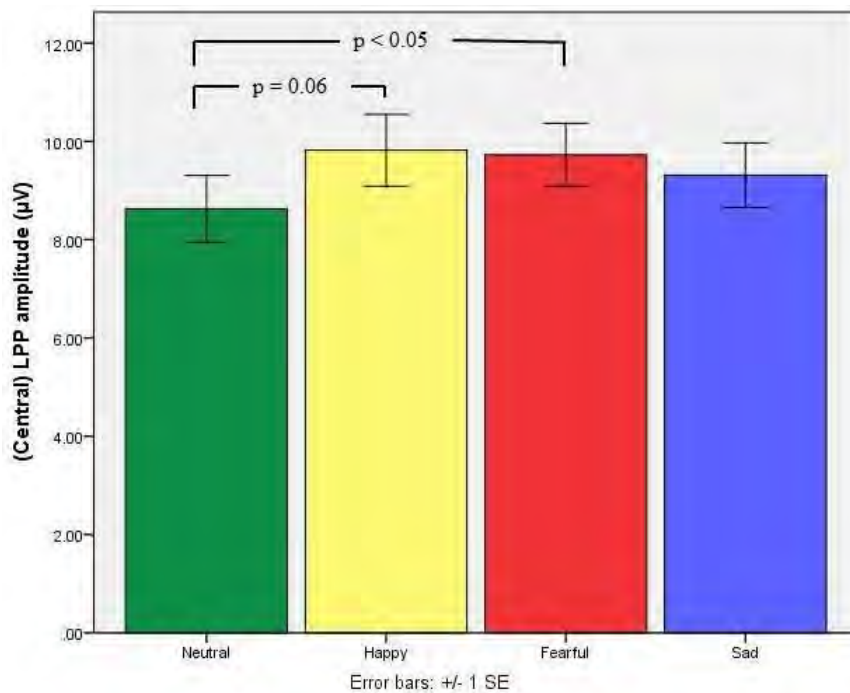
Figure 6-12. **Central LPP amplitude for upright faces (bilaterally).**

Across all groups, a main effect of emotion was found for inverted face at frontal (Fz) (F(3,105, p = 6.73, p = 0.001) and central (Cz) (F = 7.26, p = 0.001) sites, with larger amplitudes to happy compared to all other faces (all comparisons, p < 0.01) (**Figure 6-13; Figure 6-14**). Significant effect of emotion was found in both hemispheres at the frontal and central sites (both sites, p < 0.01), with larger amplitudes to happy than other facial expressions. However, although in the right hemisphere this effect showed larger amplitudes to happy than neutral and fearful (both comparisons, p < 0.02), but not sad faces (p = 0.09), only at this hemisphere a significant effect of emotion x AQ interaction (p = 0.02) was found, as will be described later.

Amplitudes for inverted faces at the central site also showed a main effect of hemisphere (F(1,35) = 19.67, p = 0.001), with larger amplitudes at the right hemisphere.

Concerning LPP latencies, analysis for inverted faces at the central site revealed a marginally significant emotion effect in the left hemisphere $(F_{(6,105)} = 2.94, p = 0.04)$, with shorter LPP latency for happy than fearful faces $(p = 0.05)$.

Concerning LPP latencies, analysis for upright faces across all AQ groups revealed a main effect of hemisphere $(F_{(1,35)} = 4.93, p = 0.03)$ at the parietal site with shorter LPP latencies in the right hemisphere.
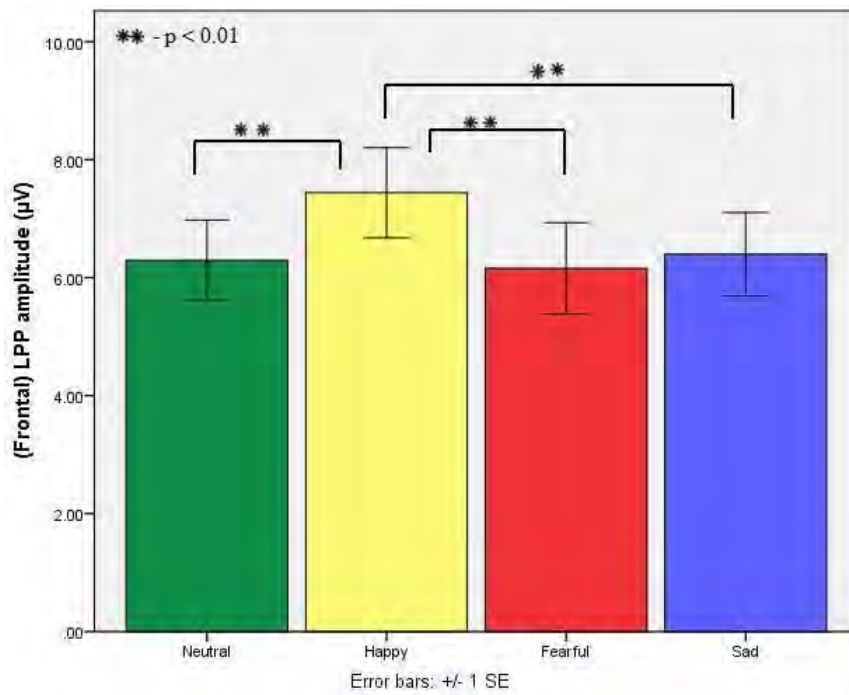
Figure 6-13. Frontal LPP amplitude for inverted faces (bilatrally).
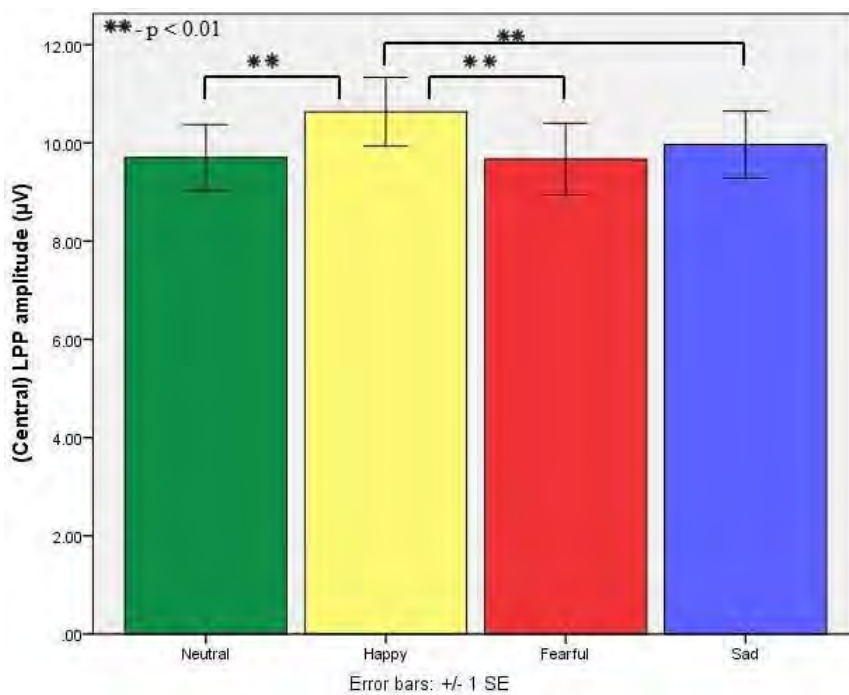
Figure 6-14. Central LPP amplitude for inverted faces (bilaterally).

6.4.2.2. Group comparisons
6.4.2.2.1. Upright vs. inverted houses
P100

A comparison between Low and High AQ groups revealed a marginal orientation x AQ interaction for P100 latencies ($F(1,23)$ = 4.05, p = 0.06) for houses. Although no significant orientation effect was found for any of groups, the main difference was that, whereas shorter latencies were found for upright compared to inverted houses in the Low AQ group, the High AQ group showed a pattern for shorter latencies for inverted houses compared to upright houses. (Low AQ: upright: 117 ms; inverted: 122 ms; High AQ: upright: 123 ms; inverted: 119 ms).

6.4.2.2.2. Upright vs. inverted faces
N170

A comparison across all three groups for N170 amplitude orientation effects across all facial expressions did not reveal significant orientation x AQ interaction effect. However, further analysis of the N170 amplitude comparing only Low and High AQ groups revealed a slight, but not statistically significant, effect of orientation x AQ interaction ($F(1,23)$ = 3.12, p = 0.09) across both hemispheres, indicating significant orientation effect across all facial expressions in the Low AQ group ($F(1,12)$ = 13.37, p = 0.003), but not in the High AQ group ($F(1,11)$ = 1.48, p = 0.25) (**Figure 6-16**). However, further analysis for each hemisphere revealed significant orientation x AQ (comparing Low and High AQ groups only) in the left hemisphere ($F(1,23)$ = 4.95, p = 0.04) (**Figure 6-15**). The orientation effect was found for the Low AQ group in the left hemisphere (F = 13.37, p = 0.003), and was marginally significant in the right hemisphere (F = 4.29, p = 0.06). No orientation effect was found in the High AQ group in the left hemisphere (p = 0.53; similarly, the right hemisphere p = 0.26).

An additional examination of orientation effect for N170 amplitude for the Mid AQ group showed a marginally significant orientation effect for this group across all facial expressions and both hemispheres ($F(1,12)$ = 11.28, p = 0.06) (**Figure 6-16**). There was significant orientation effect in the left hemisphere for this group (F = 6.03, p = 0.03), similar to the Low AQ, but in a smaller measure. In the right hemisphere this effect was marginally significant (F = 3.91, p = 0.07). Analysis of orientation effect for N170 amplitude indicate that its significance is between Low and High AQ groups, suggesting a progression in orientation effects along the level of autistic tendency (**Figure 6-15C**).

Figure 6-15. Grand-average ERP waveforms of N170 amplitude in reponse to upright and inverted facial expresssions. ERPs are recorded at P7 for upright and inverted faces collapsed across all facial expressions and are displayed for Low AQ (**A**) and High (**B**) AQ groups. Grand average of ERPs for the Mid AQ group are also shown (**C**). The inset shows position of the P7 electrode.

(A)

(B)
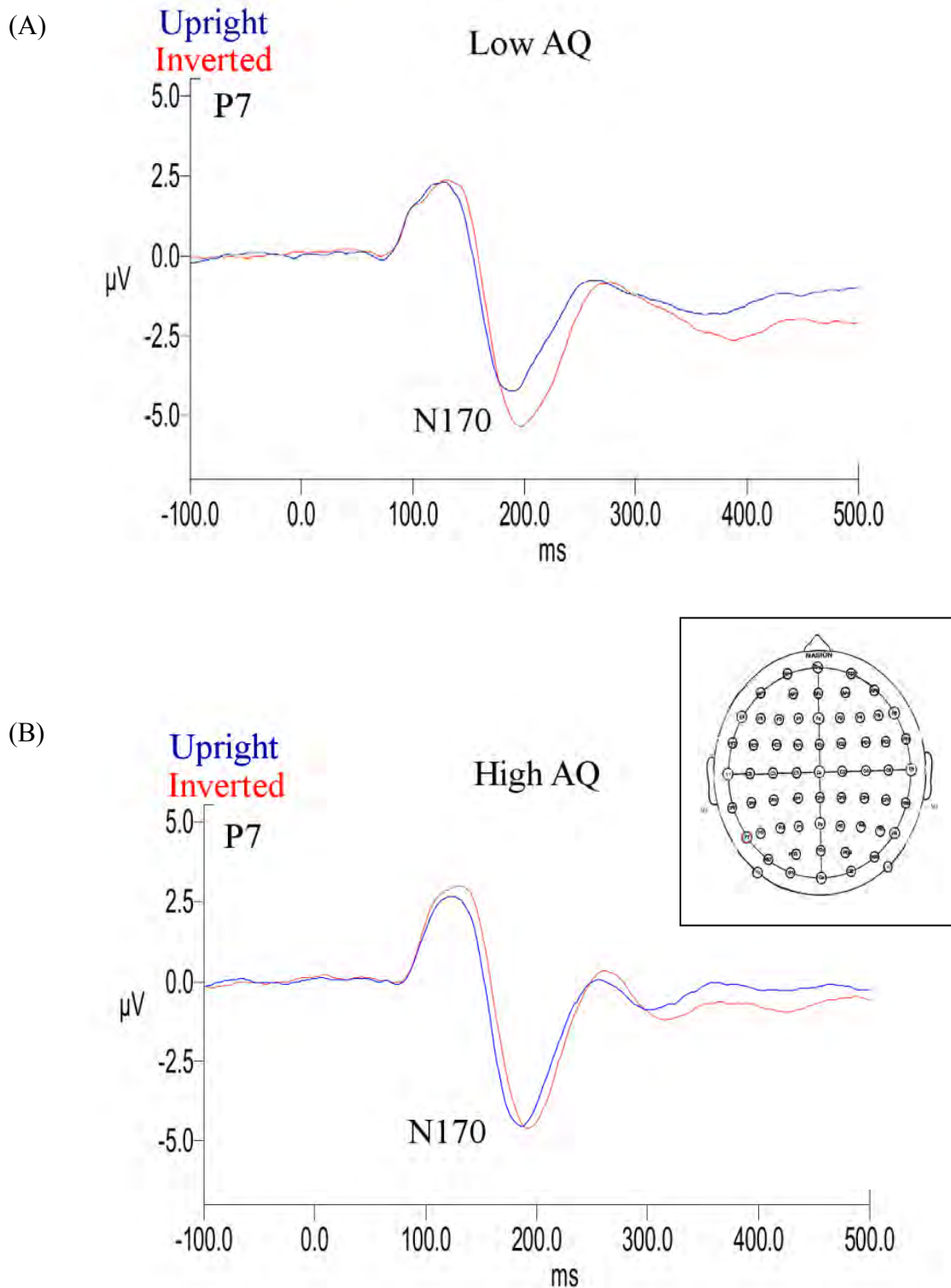
(C)
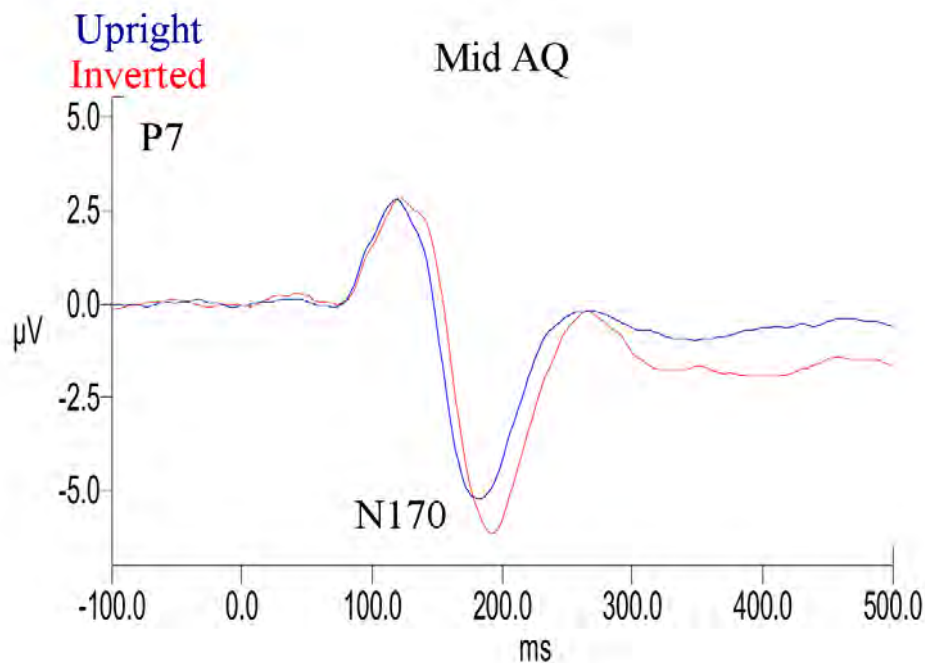
Concerning N170 latencies, all groups showed a significant orientation effect (Low: F 50.239; Mid: 34.226; High: 33.852; $p = 0.001$ for all). The Low AQ group also revealed a significant effect of emotion x orientation interaction ($F(2,26) = 3.74$, $p = 0.03$) bilaterally. The paired samples t-test revealed an orientation response for all expressions, except for sad faces in the left hemisphere ($p = 0.28$).
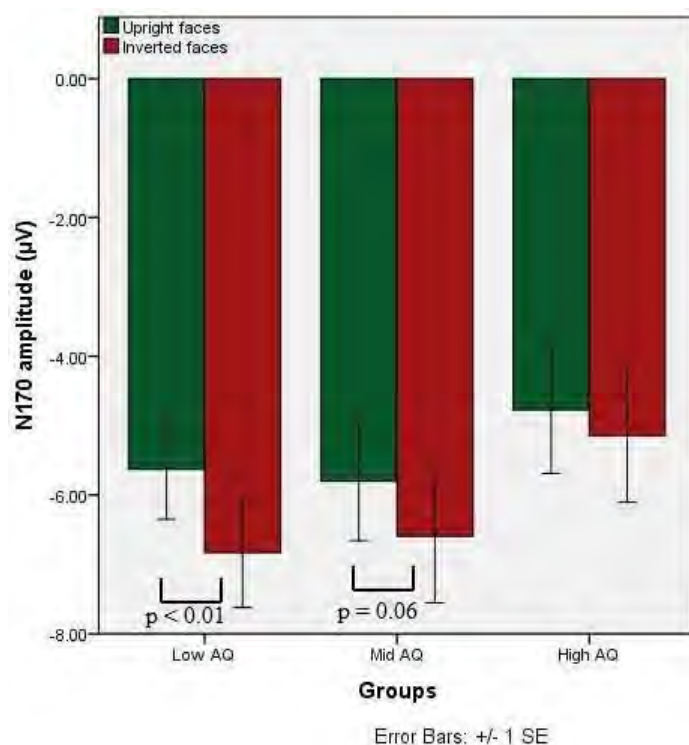
Figure 6-16.

N170 amplitude for upright and inverted facial expressions (bilaterally). Significant orientation effect for the Low AQ group was found across all facial expressions and both hemispheres. This effect was marginally significant for the Mid AQ group and absent in the High AQ group.

The topographics maps of upright and inverted facial expressions at the latency of maximum N170 amplitude (140-220 ms) for Low, Mid and High AQ groups are shown in **Figure 6-17.**

Figure 6-17. Topographic maps of upright and inverted facial expressions (across all emotions) at the latency of maximum N170 amplitude (140-220 ms) for Low, Mid and High AQ groups. Left and midle column: Topographic maps are indicating cortical activity during 140-220 ms tim period for upright and inverted facial expressions (collapsed across all emotions). Negative activity was found at posterior lateral regions for both upright and inverted faces, and this negativity was weaker in the High AQ group. Right column: difference map (inverted minus upright). Note reduced negativity (blue colour) in the High AQ group, particullary in the left hemisphere.
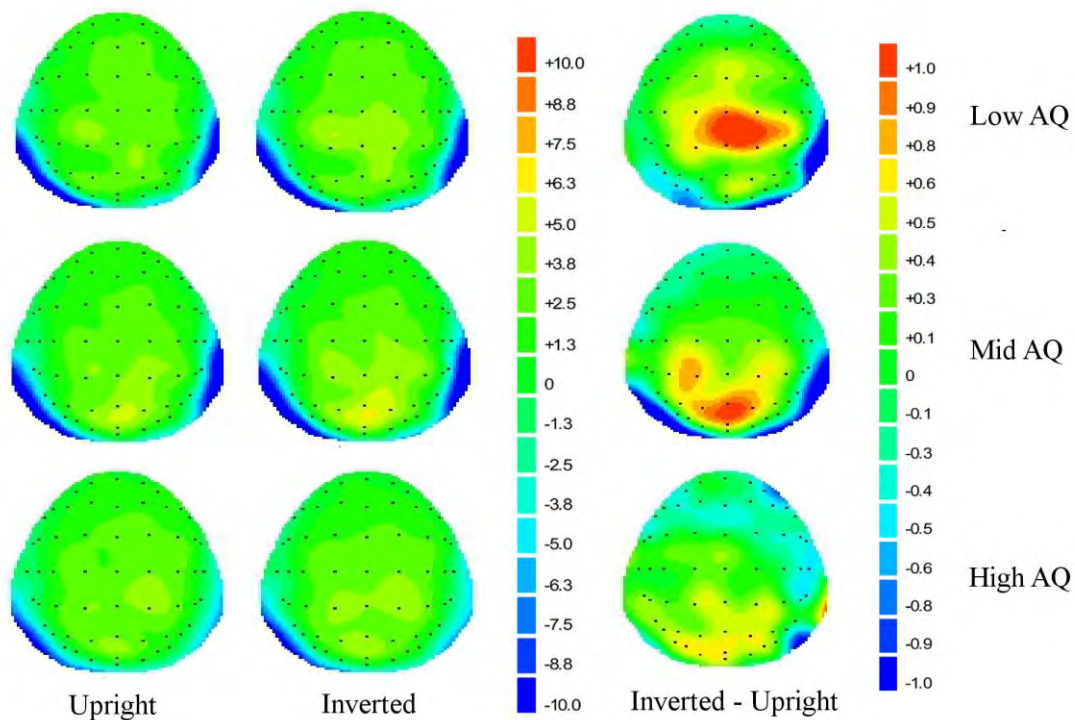
P200

A comparison between Low and High AQ groups revealed a marginally significant emotion x orientation x AQ interaction ($F_{(3,63)} = 2.57$, $p = 0.07$) for the frontal P200 amplitude. Further analysis revealed a significant orientation effect ($F_{(1,12)} = 6.49$, $p = 0.03$) for the Low AQ group **(Fig. 6-18**), with larger amplitudes for inverted faces. No orientation effect was found for the High AQ group ($F_{(1,11)} = 1.06$, $p = 0.33$). The Mid AQ group also showed significant orientation effect ($F_{(1,12)} = 16.5$, $p = 0.002$), but no orientation x AQ interaction was found when comparing the Mid AQ group with other groups.
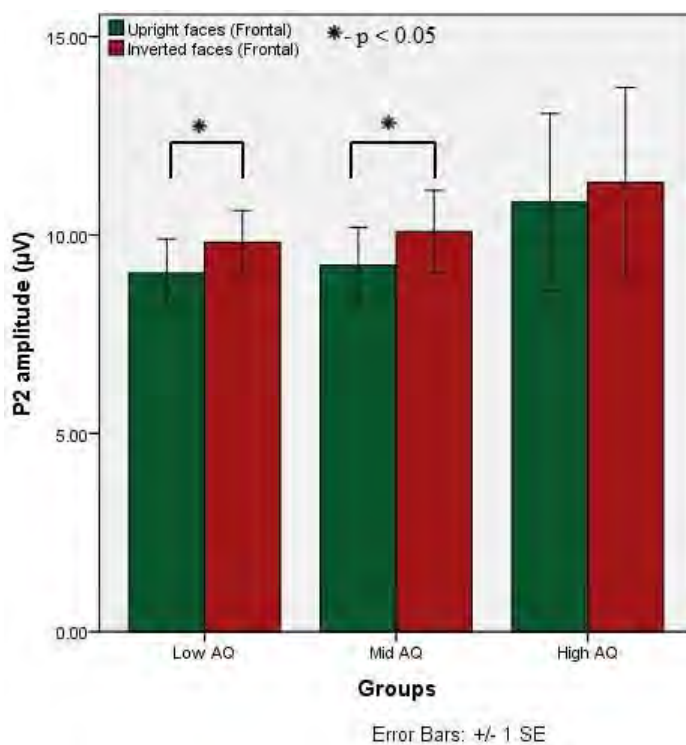
Figure 6-18.
Frontal P200 amplitude for upright and inverted facial expressions (bilaterally). Significant orientation effect was found for Low AQ and Mid AQ groups.

6.4.2.2.3. Emotion differentiation

P200

Although there were no group differences in the emotion effect for upright faces at the central P200 amplitude, a significant effect of emotion ($F_{(3,36)} = 4.88$, $p = 0.01$) was found for the the Low AQ group, with larger amplitudes to all facial expression compared to neutral faces ($p < 0.05$ for all comparisons) bilaterally. No emotion effect was found for High and Mid AQ groups.

However, results for the central P200 amplitudes when comparing Low and High AQ groups revealed a marginally significant emotion x AQ interaction ($F_{(3,69)} = 2.49$, $p = 0.07$)

in the right hemisphere for inverted faces. An additional comparison showed a marginal emotion x AQ interaction effect when comparing Mid and High AQ groups in the right hemisphere $(F_{(3,69)} = 2.64, p = 0.06)$. Further ANOVA revealed a significant emotion effect $(F_{(3,33)} = 4.58, p = 0.01)$ for the High AQ group for inverted faces in the right hemisphere, with larger P200 amplitudes for sad compared to neutral faces $(p = 0.01)$, and a tendency for larger amplitudes for fearful than neutral faces, but with no statistical significance $(p = 0.08)$ (**Figure 6-19**). No significant emotion effect was found for other groups

LPP

Analysis for the central LPP revealed a statistically significant emotion x AQ interaction $(F_{(3,69)} = 2.95, p = 0.04)$ for inverted faces and across both hemispheres when comparing Low and High AQ groups. Results for the High AQ group showed significant effect of emotion $(F_{(3,33)} = 6.44, p = 0.001)$ for inverted faces, with larger amplitudes to happy than to neutral $(p = 0.01)$, fearful and sad faces (both, $p = 0.05$). Emotion differentiation for the High AQ group was also found in each hemisphere, showing larger amplitudes for inverted happy than neutral faces in the left hemisphere, and larger amplitudes for inverted happy than neutral $(p = 0.01)$ and fearful $(p = 0.03)$ faces in the right hemisphere. However, statistically significant emotion x AQ interaction was found only in the right hemisphere, both when comparing only Low and High AQ groups $(F_{(3,69)} = 4.33, p = 0.01)$, and also when comparing all three groups $(F_{(6,105)} = 2.79, p = 0.02)$. (**Figure 6-19** shows the P200 and LPP amplitudes at the central site for Low and High AQ).

Concerning frontal LPP amplitudes, although not significant, some emotion x orientation x hemisphere x AQ interaction $(F_{(6,105)} = 1.96, p = 0.08)$ was found. Further analysis for the High AQ group showed emotion effect (bilaterally) for inverted face, $(F_{(2,22)} = 5, p = 0.02)$, with larger amplitudes for happy compared to neutral and sad faces (both comparisons, $p < 0.01$).

An important finding is that only the High AQ group showed significant emotion x orientation interaction for both central $(F_{(2,23)} = 4.12, p\ 0.03)$ and frontal $(F_{(2,22)} = 3.78, p = 0.04)$ LPP amplitudes.

The topographic maps at the peak of the P200 and LPP components in responses to inverted facial expressions in Low and High AQ groups are displayed in **Figures 6-20 and 6-21.**

Figure 6-19. P200 and LPP amplitudes at the central site for High (A) and Low (B) AQ groups. Inserted image shows position of C4 electrode.
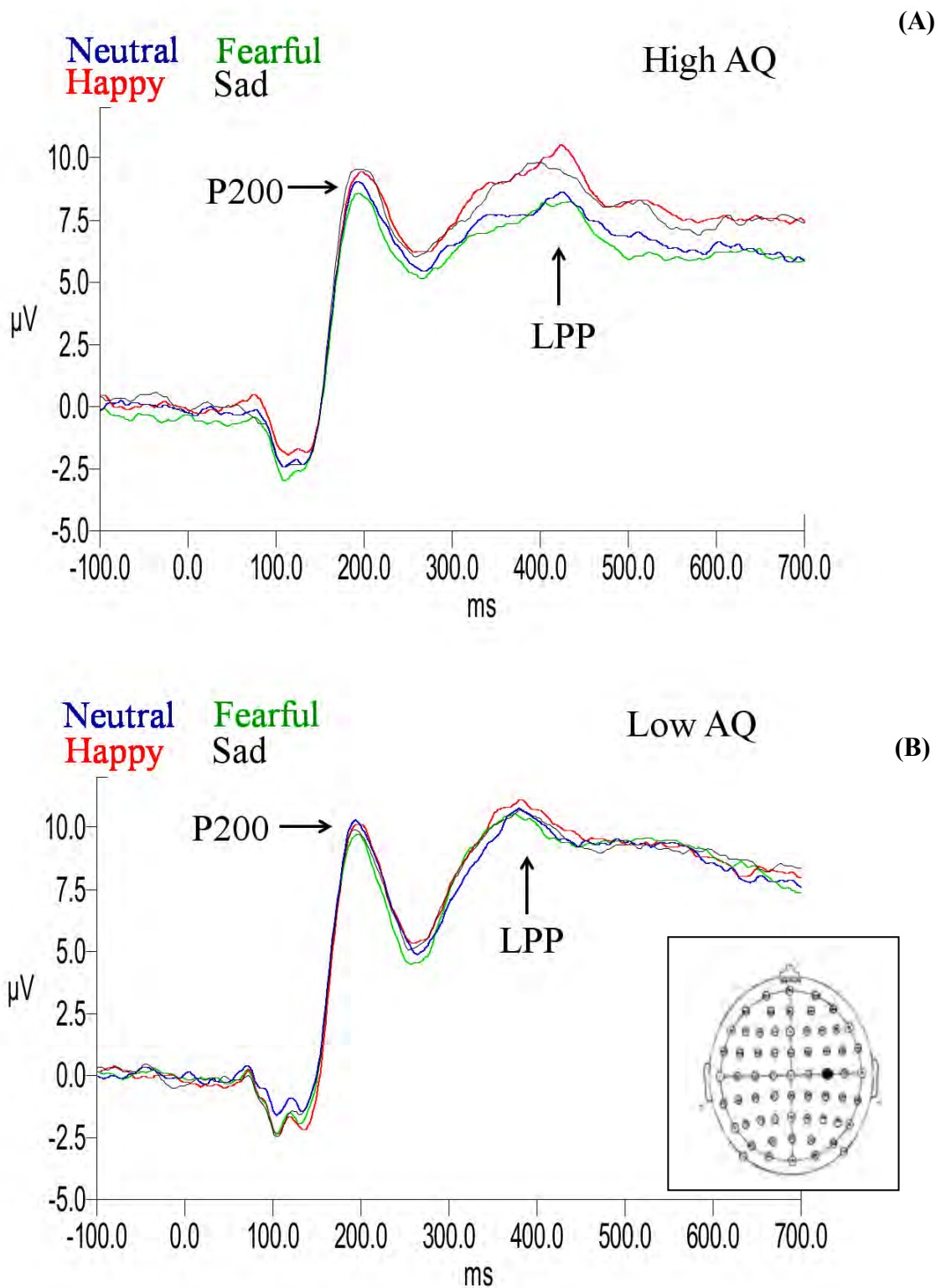
Figure 6-20. Scalp topographies at the maximum peak of the P200 component in responses to inverted facial expressions in Low and High AQ groups. The topographic plots are snapshots of the P200 response at the C4 electrode. A stronger activity can be seen in the Low AQ group for all facial expressions, but greater variability in responses between facial expressions can be seen for the High AQ group. The circle shows the position of the C4 electrode.
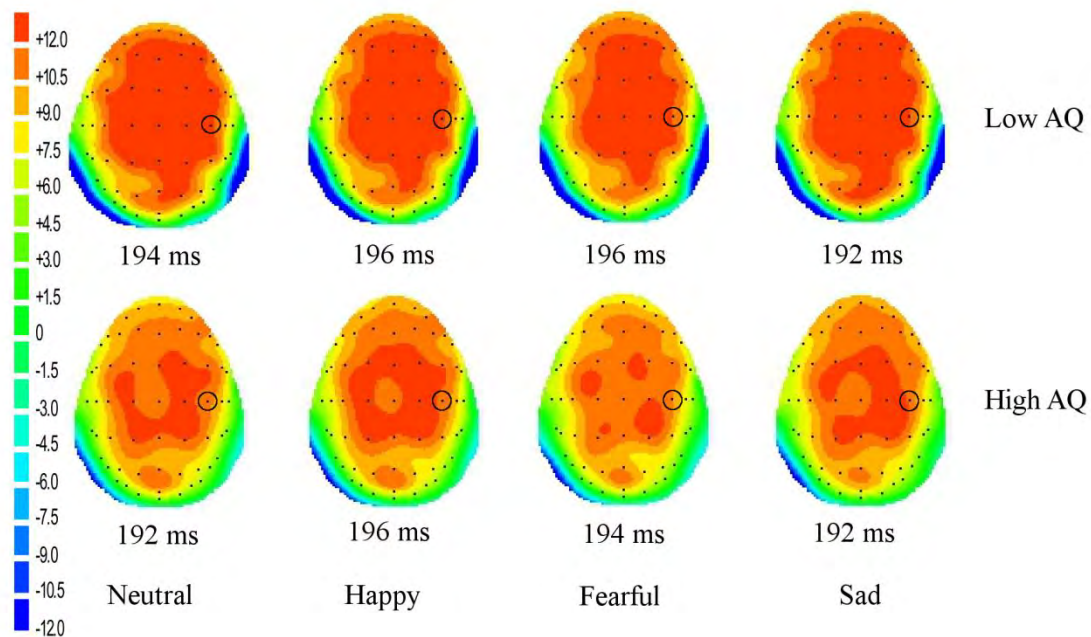
6.4.3. Correlational analyses

Pearson correlation was performed between AQ and EQ scores, and also between EQ scores and ERPs, mostly between Low and High AQ groups

6.4.3.1. Correlations between measures

Across all participants

A negative correlation was found between AQ and EQ scores, and a positive correlation between AQ scores and Raven's scores (**Table 6-4**).

Figure 6-21. Scalp topographies at the peak of the LPP component in responses to inverted facial expressions in Low and High AQ groups. The topographic plots are snapshots of the LPP response at the C4 electrode. A stronger activity can be seen for happy and sad facial expression compared to neutral and fearful expressions in the High AQ group.
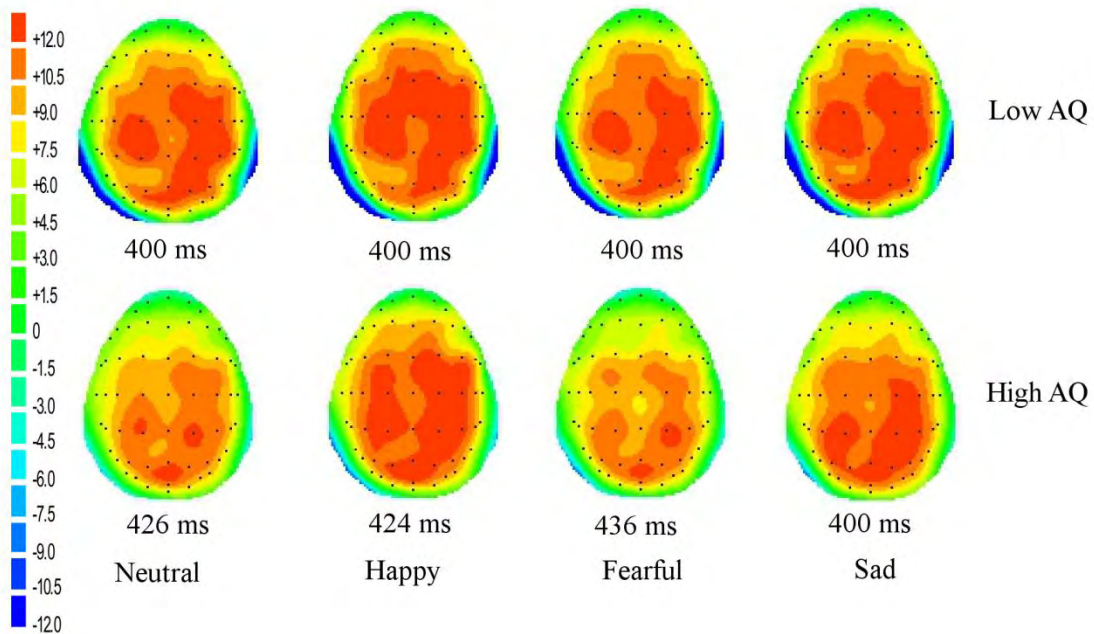
Table 6-4. Correlations

		AQ score	EQ score	Raven's
AQ score	Pearson Correlation	1	-.796[**]	.331[*]
	Sig. (2-tailed)		.000	.045
	N	38	38	37
EQ score	Pearson Correlation	-.796[**]	1	-.317
	Sig. (2-tailed)	.000		.056
	N	38	38	37
Raven's	Pearson Correlation	.331[*]	-.317	1
	Sig. (2-tailed)	.045	.056	
	N	37	37	37

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Groups

For the Low AQ group, analysis did not reveal any correlation between AQ and EQ scores. For the High AQ group, AQ scores were negatively correlated with the EQ scores ($r = -0.88$, $p = 0.001$) (**Figure 6-22**). Raven's correlated positively with AQ scores ($r = 0.75$, $p = 0.01$), and negatively with EQ scores ($r = -0.68$, $p = 0.02$). For the Mid AQ group, the AQ score correlated negatively with the EQ ($r = -0.68$, $p = 0.01$).

Figure 6-22.Correlation between AQ and EQ scores for the High AQ group.
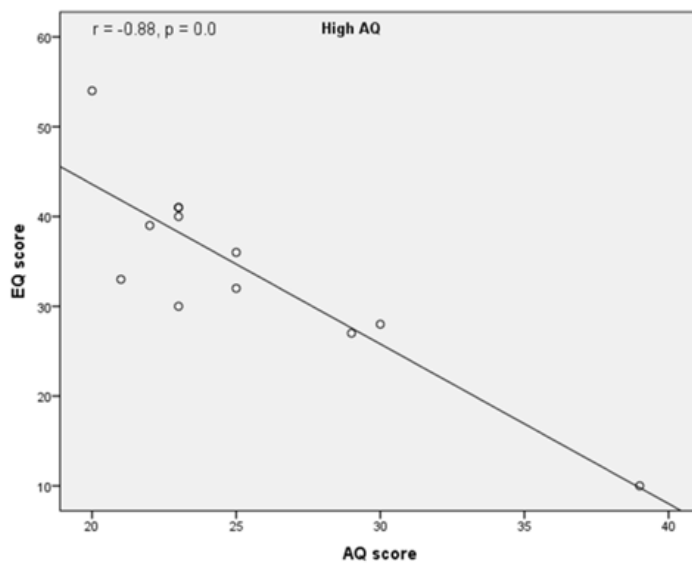
6.4.3.2. Correlation analyses between measures and ERPs

Pearson correlations between measures (AQ scores, EQ scores, Raven's) and ERPs were computed for Low and High AQ groups.

EQ Correlations

For the *Low AQ* group, the EQ was negatively correlated with P100 latencies for upright houses (at O2) ($r = -0.61$, $p = 0.03$). For this group, EQ scores were positively correlated with N170 latencies for upright happy ($r = 0.58$, $p = 0.04$) and fearful faces (both at P8) ($r = 0.56$, $p = 0.05$), and negatively correlated with P200 amplitudes for upright neutral ($r = -0.58$, $p = 0.04$) and upright fearful ($r = -0.7$, $p = 0.01$) faces (both at C4). No correlation was found between EQ scores and LPP component in this group.

For the *High AQ* group, no significant correlation was found between EQ scores and the P100 component. This group showed a negative correlation between EQ scores and N170 latencies for inverted houses at P7 ($r = 0.58$, $p = 0.05$). A positive correlation was found between EQ scores and P200 amplitudes for upright neutral (at C3: $r = 0.71$, $p = 0.02$; at C4: $r = 0.64$, $p = 0.03$), fearful (C3) ($r = 0.63$, $p = 0.04$), and sad (C3) ($r = 0.69$, $p = 0.02$) faces, and P200 amplitudes for inverted neutral faces (C3) $r = 0.61$, $p = 0.05$). A negative correlation was found between EQ scores and P200 latencies for upright sad faces (C4) ($r = -0.61$, $p = 0.05$) in this group. The EQ was negatively correlated with LPP latencies for upright neutral faces (at P300) ($r = -0.58$, $p = 0.05$).

AQ Correlations

For the *Low AQ* group, there was a positive correlation between AQ scores and LPP latencies for inverted neutral faces (at C3) ($r = 0.64$, $p = 0.02$), and upright fearful (P300, $r = 0.58$, $= 0.04$) and sad faces (at C3) ($r = 0.67$, $p = 0.01$).

For the *High AQ* group, there was a positive correlation between AQ scores and N170 latencies for upright houses (P7, 0.61, $p = 0.04$) and also inverted houses (P7, $r = 0.6$, $p = 0.04$). For this group, there was a positive correlation between AQ scores and P200 latencies for upright neutral (C4, $r = 0.63$, $p = 0.03$), happy (C4, $r = 0.67$, $p = 0.02$), fearful (C4, $r = 0.66$, $p = 0.02$) and sad faces (C4, $r = 0.67$, $p = 0.02$), and for inverted happy faces (C4, $r = 0.64$, $p = 0.03$). AQ scores also correlated with P200 amplitudes for upright sad faces (C3, $r = -0.6$, $p = 0.04$, C4, $r = -0.58$, $p = 0.05$).

6.4.3.3. Summary of correlational findings

First, in the Low AQ group, correlation of the EQ with ERPs was mostly found in the right hemisphere, whereas in the High group it was found predominantly in the left hemisphere. Next, correlation between the EQ and inverted stimuli was found only in the High AQ group (for inverted houses and inverted neutral faces). Finally, an important observation is an absent correlation of the EQ and processing of faces in the N170 for the High AQ group.

Results showed an inverse correlation between AQ and EQ scores in High AQ groups (also in the Mid AQ group). Baron-Cohen and Wheelwright (2004) consider the inverse correlation between the AQ and the EQ as one indicator of the validity of the EQ, because the

AQ measures domains that require empathy, such as social sensitivity and sensitive communication. No correlation between AQ and EQ scores was observed in the Low AQ group.

6.4.4. Summary of results

Overall, larger P100 and N170 amplitudes for faces than for houses were found in all participants, as have been demonstrated in previous studies that compared faces and objects (Rossion et al., 1999; Itier, Latinus, & Taylor, 2006; Itier & Taylor, 2004a). The finding of larger amplitude for faces in the N170 is consistent with the proposed specialisation of the N170 component for the processing of faces, and represents an early stage of face recognition and analysis of facial features and configuration (Bentin et al., 1996; Bentin, Deouell & Soroker, 1999; but see Rossion et al., 1999).

Across all groups, the face inversion effect was evident in the P100 visual component, with faster speed processing for upright compared to inverted faces, which is consistent with literature (Rossion et al., 2000; Sagiv & Bentin, 2001), and in the N170 for both amplitudes and latencies. The face inversion effect was also present in the central P200, but disappeared in the parietal LPP. Low and High AQ groups differed in the face inversion effect primarily at the N170, although group differences were found only in the left hemisphere.

The most significant finding with regard to group differences in emotion differentiation is seen in the P200 component, showing enhanced central P200 amplitude to inverted sad faces only in the High AQ group.

6.5. Discussion

The primary objective of the present study was to investigate the face inversion effect in individuals with lower and higher autistic traits in early and later ERP components. Although some previous studies suggested that the differentiation of upright and inverted faces starts during early perceptual encoding beginning as early as 110-130 ms from stimulus onset (e.g., Jacques & Rossion, 2007), face inversion effects on the early P100 component are not so robust as face inversion effects occurring at the N170 component. In the present study, upright faces showed shorter P100 latencies compared to inverted faces regardless of autistic tendency, although no inversion effect was found for amplitudes. It is suggested that the P100 component is responsive for making the decision that the stimulus is a face, and this is happening through first order processing of the basic structure of the face (Maurer, Le Grand,

& Mondloch, 2002). Thus, it can be suggested that there is no difference between individuals with higher and lower autistic traits at this stage of face processing. Across all groups, the N170 exhibited larger amplitudes and longer latencies for inverted facial stimuli, replicating the findings of previous ERP studies comparing upright and inverted faces (e.g., Itier, & Taylor, 2002; Rossion et al., 2000b). Larger amplitudes were observed for inverted than upright faces at frontal and central P200 and LPP components, and shorter latencies for upright compared to inverted faces were found at the frontal P200. It is suggested that the P200 component reflects deeper processing that helps in categorising ambiguous stimuli (Itier & Taylor, 2004a), and may be sensitive to the facial configuration (Boutsen et al., 2006; Halit et al., 2000), with some studies observing larger amplitudes to upright than inverted faces at frontal (Ashley et al., 2004) or at parietal sites (Pesciarelli et al., 2011). In some other studies an effect of orientation was observed on longer-latency ERP components in frontal sites only (Ashley et al., 2004), or in frontal and parietal sites, suggesting that inversion can affect face recognition until about 500 ms from stimulus onset (Marzi, & Viggiano, 2011). In the present study, the face inversion was not seen in parietal site, but only in frontal and central sites.

The data in this study suggests that rapid analysis of the face configuration at the level of basic visual recognition at the P100 ERP component over occipital region does not differ between individuals of different autistic tendencies. However, results showed a significant influence of the level of autistic tendency on the face inversion effect observed in the N170, with larger amplitudes for inverted than upright faces found in Low and Mid AQ groups but not the High AQ group, with significant group differences found in the left hemisphere. The face inversion effect is generally absent or reduced in individuals with autism. Although some studies did not find differences in the N170 amplitudes for inverted and upright faces between autistics and controls (Webb et al., 2012), other studies indicated reduced N170 amplitudes for inverted relative to upright faces in individuals with autism (McPartland et al., 2011). We did not find any group differences in orientation effect for the N170 latency, and this may be in agreement with some previous studies with autistic subjects that did not observe significant differences in N170 latencies for upright versus inverted faces in individuals with autism compared to healthy controls (McPartland et al., 2004; McPartland et al., 2011; Webb et al., 2012). In summary, the current study indicates that differences between Low AQ and High AQ groups with regard to upright and inverted faces are comparable to at least one study comparing adults with autism and the healthy control (McPartland et al., 2011) that observed similar patterns of amplitudes and latencies for the N170 component, and that the inversion

effect in the N170 is larger with higher AQ scores. It is suggested that insensitivity to the face inversion, as well as delayed processing of faces at the N170, as often observed in individuals with autism (e.g. McPartland et al., 2011), is a result of reduced attention to faces during early development, which is not conductive for developing specialisation for faces as in typically developing children (Dawson et al., 2005; McPartland et al., 2011). Although our study did not include autistic subjects, it extends previous findings on autism by showing that differences in the face inversion effect between people with lower and higher autistic traits can be observed in later components, particularly the P200.

Overall, the findings on the face inversion effect in individuals with different levels of autistic tendencies are in line with research on individuals with autism, who have been found to have reduced or absent inversion effects, explained by enhanced featural processing in this group (Wolf et al., 2008). There is substantial support for the importance of configural information in face perception (see Kimchi & Amishav, 2010; Maurer, Le Grand, & Mondloch, 2002). Some recent research suggests that individual differences in processing global visual information can have a significant impact on face perception. For example, in a recent study (Martin & Macrae, 2010) the face inversion effect was used to test participants divided into groups of those showing strong global precedence and those showing weak global precedence, and the results showed smaller face inversion effect and poorer recognition of upright faces in participants with weak global precedence. Global precedence was based on participants' responses on the non-face local-global task and the Navon figures task, in which participants are presented with a large letter made up of small letters and are required to recognise letters at the global or local level (Navon, 1977). Some previous studies with the Navon figures task found absent global precedence in children with autism compared to neurotypical children, although only under the condition of divided attention where children were not given information at which level, either global or local, to attend (Plaisted, Swettenham, & Rees, 1999). Further support for the importance of configural information in face processing is coming from studies on priming. For example, previous research with healthy subjects found substantial face recognition deficiency followed by encouraging feature-based processing, such as by priming with local Navon figures (Macrae & Lewis, 2002), or by disrupting configural processing of faces by using composite faces task (Young, Hallawell, & Hay, 1987).

These results give partial evidence for the weak central hypothesis of autism. The weak central coherence (WCC) theory of autism (Frith & Happé, 1994; Happé & Frith, 2006) states that individuals with autism have a tendency for relative primacy of local processing but deficits in global processing of information. On the other side, healthy people mostly show preference for a global processing style. The WCC predicts that individuals with autism will show a weakness in configural processing. Additionally, the Enhanced Perceptual Functioning (EPF) model of Mottron et al., (2006) suggests that individuals with autism possess a superior recognition of detailed information, without a complete absence of ability for generating a whole. While support for the weak central coherence theory was already found in autism research, although with mixed results (for a detailed review of studies see Happé & Frith, 2006), recently Grinter et al., (2009) found that individuals with higher autistic traits show superior performance on the EFT task (which requires identifying smaller geometric shapes embedded within a more complex form), suggesting local processing advantage for this group. Similarly, Wyer et al., (2012) combined scores on the Empathy Quotient (EQ) and Systemizing Quotient (SQ) scales to get a measure of AQ (Wheelwright, Auyeung, Allison, & Baron-Cohen, 2006) and found that individuals with systemising bias in cognitive style are better at the EFT task than individuals with balanced or empathising cognitive styles.

The results of our study are in a partial agreement with a previous behavioural study that showed that higher AQ scores predict a smaller face inversion effect (Wyer et al., 2012), with a gradual decrease of the faces inversion effect with an increase of AQ score. However, an advantage of the present study is that it shows neural correlates of the inversion effect, suggesting that a gradual decrease of the face inversion effect in individuals with higher autistic tendencies is observed only for the N170 component.

6.5.1. Emotion differentiation

Emotion effects across all groups were found already in the early visual component, the P100, and at lateral occipital electrodes, showing larger amplitudes for upright fearful faces compared to other facial expressions, supporting previous findings of enhanced processing of threatening facial expressions at the P100 (e.g., Batty & Taylor, 2003; Batty & Taylor, 2006; Meaux, Roux, & Batty, 2013). It is still debatable whether the early face-sensitive component, the N170, is modulated by different facial emotional expressions, although more studies now support modulation of this component by emotional faces (e.g.,

Blau et al., 2007). The current study provides further support for modulation of the N170 by different facial expressions by showing enhanced N170 amplitude for upright happy and fearful faces. This observation relates only to findings across all subjects, as no group differences emerged for emotion discrimination at the N170. This could suggest that emotion modulation at the N170 is not completely absent, but is influenced by individual differences between participants. Our study is specific in including subjects with high autistic traits, and some of them had very high AQ scores of 39, and scores above 32 are found to be prevalent (72%) in individuals with Asperger's and high functioning autism with only a minority (2%) of neurotypically developing individuals achieving this score (Baron-Cohen et al., 2001). In addition, the overall emotion effect on this component was very small (p = 0.04). As we did not find modulation of the N170 by inverted faces, an exclusive configural explanation for emotion modulation for this component (Ashley et al., 2004) cannot be confirmed.

Significant emotion differentiation was found at the P200 component across all groups, particularly expressed by enhanced central P200 amplitudes for all emotional expression compared to neutral faces. The finding of enhanced sadness in the inverted orientation for this component is in disagreement with previous studies that proposed that emotional modulations of the P200 ERP component are not based exclusively on low-level visual feature differences (Ashley et al., 2004). However, Ashley et al., (2004), who found emotion modulation for this component only for upright faces, did not examine sad faces. In another study, Eimer and Holmes (2002) showed enhanced amplitudes for both upright and inverted fearful faces over the time window of this component for fronto-central electrodes. The P200 amplitude is considered to have an origin at the visual association cortex (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001a) and is suggested to be an index of attention towards valence of the stimuli, mainly at frontal and central sites (Carretié et al., 2001a; Carretié, Mercado, Tapia, & Hinojosa, 2001b). Some other studies have indicated that emotional effects on ERPs start with this component (Eimer et al., 2003).

The most important finding concerning emotion modulation and group differences is the evidence of emotion modulation for inverted faces found in the High AQ group only. This modulation was expressed as enhanced central P200 amplitude in the right hemisphere for inverted sad faces, and enhanced central LPP in the right hemisphere for happy faces. These results suggest that emotional differentiation in the central P200 and LPP in the right hemisphere is influenced by visual properties of stimuli in the High AQ group only.

Additional important group differences were found at the parietal P200 by using one-way ANOVA. Results indicated faster speeds of processing of inverted facial expressions (neutral, happy and fearful) in the Low AQ group. Previous studies have suggested that the P200 may reflect the speed of face cognition and deeper processing of stimuli (Latinus, & Taylor, 2005). Delayed latencies have been previously shown in individuals with autism, but mostly on early visual ERPs. Several studies have reported delayed latencies for faces in individuals with autism compared to neurotypical individuals for both P100 and N170 (O'Connor et al., 2005) or for the N170 only (McPartland et al., 2011). McPartland et al., (2011) found longer N170 latencies for faces in individuals with autism compared to typical individuals, and also found that a neurocognitive test that assesses recognition memory for faces (Faces Subtest, Wechsler, 1997) correlated significantly with the speed of face processing (N170 latency) for both upright and inverted faces. Delayed latencies for both P100 and N170 ERPs were also found in another study with adults with Asperger's syndrome (O'Connor et al., 2005). In a behavioural study, Behrmann et al., (2006) found slower face discrimination in individuals with autism, and the authors explained this by "the visual bias towards the local elements and perhaps simultaneous or resultant difficulty in integrating local components of a stimulus into a whole" (p. 124). Slowed face processing in early ERPs may indicate that individuals with autism employ qualitatively different strategies for face processing (McPartland et al., 2011) and need longer time to recruit neuronal networks involved in configural face processing (O'Connor et al., 2005). Slowed processing of faces may also be detrimental for developing expertise with faces, and as social information is complex and requires rapid integration of information, slowed speed of processing of faces may influence many aspects of social functioning (McPartland et al., 2011). However, our data cannot confirm previous findings of atypical speeds of processing in early, P100 and N170 components during face processing observed in individuals with autism, but we can conclude that the speed of processing at the P200 can be an important marker of different processing of the configural characteristic of facial expressions in individuals with high autistic traits. Closely related to this is another important finding in the present study that indicated that, regardless of the AQ group, the faster processing of inverted facial expressions is related to higher scores on the EQ and, additionally, lower AQ scores. This finding emphasizes the importance of latencies at the P200 component for group difference between individuals with different levels of autistic traits and social cognition in general.

Enhanced LPP for inverted happy faces was also found, suggesting that this component is also affected by configuration, rather than emotional content of sad faces. Previous studies indicated that posterior LPP might be enhanced by the arousal value of the stimuli rather than the specific emotional valence. This would suggest that this ERP does not represent just a difference between positive and negative emotions (Hajcak, MacNamara, & Olvet, 2010; Schupp et al., 2000), but may be enhanced even by arousing objects (Key, Jones, & Dykens, 2013) or motivationally salient stimuli (Hajcak et al., 2010).

In the present study, group differences for LPP amplitudes showed emotion modulation of this component in the Mid AQ only, with enhanced amplitudes for upright fearful faces (right hemisphere and midline electrodes). The only known study (Nixima, Fujimori, & Okanoya, 2013) that examined the LPP during emotion processing in individuals with different levels of autistic traits found larger LPP amplitudes in the Mid AQ group compared to the High AQ group in responses to angry and happy facial expressions. Nixima et al., (2013) suggested that the AQ can be sensitive to the differences in emotional processing in high or medium autistic traits, but might not be sensitive enough for capturing variability in low autistic traits. The results of our study would partially agree with this notion, proposing that configural processing of faces/facial expressions rather than emotional processing per se is more important for explaining differences in emotion processing in groups with different levels of autistic traits. Studies with autistic subjects have supported the importance of configural aspects of faces in facial emotion processing. For example, the face specific N170 has been widely accepted as an index of configural processing (O'Connor et al., 2005; Taylor, Batty, & Itier, 2004a; Taylor & Smith, 1995). In a study with autistic subjects, O'Connor et al., (2005) found significantly decreased N170 amplitudes to all facial expressions in adults with Asperger's syndrome compared to neurotypical adults. This finding was taken as an argument for impaired processing of facial configuration rather than emotion per se in adults with Asperger's syndrome (O'Connor et al., 2005). Our study partially corroborated these findings by showing a tendency in the High AQ group to have smaller N170 amplitudes for faces compared to the Low AQ group, although with no significant group differences.

Recent studies on face perception have indicated that both configural and featural information are necessary for processing of facial identity, supporting a dual-code view of face perception (Cabeza & Kato, 2000; Leder & Bruce, 2000). Findings suggest that featural

and configural information is processed by a distinct neural pathway (Cabeza & Kato, 2000; Lobmaiera, Klavera, Loennekerb, Martin, & Mast, 2008; Rossion et al., 2000). However, not many studies have examined the role of configural and featural processing in the recognition of facial emotional expressions (Bombari et al., 2013). Some studies have shown a decrease in emotion recognition sensitivity when facial emotional expressions were inverted, suggesting an important role of configural information in facial emotion processing (Chambon, Baudouin, & Franck, 2006; Derntl, Seidel, Kainz, & Carbon, 2009; McKelvie, 1995; Prkachin, 2003). However, some other studies have suggested that both featural and configural information may have an important role in different expressions based on their specific physical characteristics. For example, a smile is suggested to be important and sufficient for recognising happiness (Leppänen & Hietanen, 2004), and eyes, especially wide open eyes, are important for recognition of fear (Adolphs et al., 2005; Dadds et al., 2006). It is not clear whether fear is affected by turning faces upside down, as some behavioural studies found it to be less affected by face inversion compared to happiness, sadness and anger (Bombari et al., 2013), and some other studies found that its recognition is significantly affected by inversion (Prkachin, 2003). Ashley (2004) suggested that processing of fearful faces is not dependent on any configural cues because enhanced fearful faces were observed only in upright orientation but not in inverted orientation for face-specific components, particularly the P200. Our study is in partial agreement with this statement as we observed absent inversion for fearful faces in the N170 (left hemisphere) and at the central P200 (right hemisphere).

However, some facial expressions cannot be extracted from looking at any particular feature but this is achieved in a more configural way. For example, happiness has been suggested to be recognisable by both looking at global configuration of the face or by looking at the mouth (Adolphs, 2002). Concerning other expressions, this has also been proposed for the recognition of sadness (Bombari, et al., 2013; McKelvie, 1995; Prkachin, 2003). Although several studies that examined eye movements during various facial expressions showed the importance of attention to the eyes for recognition of sad facial expressions (e.g., Smith, Cottrell, Gosselin, & Schyns, 2005; Williams, Senior, David, Loughland, & Gordon, 2001), sadness was found to be more dependent on configural than featural information. This can be seen in physical properties of sad faces that do not have highly distinctive features, and therefore requires observing the interrelationship between features (Bombari et al., 2013). This can possibly explain findings of a behavioural study (Chambon, Baudouin, & Franck,

2006) that indicated that the discriminability of sadness dropped more than other facial expressions when faces were inverted, with happiness showing the least difficulty in discriminability.

Recognition of sad faces was found to be impaired in behavioural studies with autistic subjects (e.g., Boraston, Blakemore, Chilvers, & Skuse, 2007; Wallace et al., 2011). Wallace et al., (2011) used morphing images and found that individuals with autism needed higher intensity for recognising sadness, although this finding was not supported after using Bonferroni correction, and diminished recognition of sadness was correlated with social-communicative symptoms as measured by the ADOS. Difficulty in recognising sadness, together with anger and disgust, and a need for higher intensity in this expression was also found in a greater measure in the High AQ group compared to the Low AQ group (Poljac, Poljac, & Wagemans, 2012). Boraston et al., (2007) found that individuals with autism have difficulties in recognising sadness in both facial stimuli and in animations. O'Connor et al., (2005) found that recognition of neutral and sad facial expressions improves with age in neurotypical adults, but not in individuals with Asperger's syndrome. Difficulties in recognising those emotions were proposed to stem from their complexities and an association of sadness with empathy (O'Connor et al., 2007). Similarly, in a study with non-autistic subjects, recognition of sadness was considered as a marker of emotional empathy and was found to be impaired in psychopathy (Woodworth & Waschbusch, 2008). Reduced recognition of sadness was also reported in a group of boys on the autistic spectrum that showed externalising behaviour problems (Rogers, Viding, Blair, Frith, & Happé, 2006).

The present study also showed enhanced LPP amplitudes for inverted happy faces only in the High AQ group. Previous research has proposed that emotion discrimination found at P300b and LPP components reflects processing resources to stimulus evaluation (Folstein & Van Petten, 2011; Polich, 2012), and elaborative processes during categorical discrimination of stimuli (Schacht & Sommer, 2009). Recently Calvo and Betran (2014) found enhanced P300b (within 350-450 ms latency) amplitude for the bottom half of happy faces, whereas LPP (within 450-600 ms) was enhanced for the top half of angry faces. They interpret findings as showing that an expressive source of a face contributes to categorization of facial expressions at this stage. The smiling mouth is considered to be highly diagnostic for happiness recognition (Calder et al., 2000; Calvo, Fernández-Martín, & Nummenmaa, 2014; Calvo & Betran, 2014; Nusseck, Cunningham, Wallraven, & Bülthoff, 2008; Smith et al.,

2005; Wang, Friel, Gosselin, & Schyns, 2011). The smile as a distinct facial feature has been proposed to represent a shortcut for categorization of a face as happy (Adolphs, 2002; Leppänen & Hietanen, 2007) and could account for advantage of happy facial expressions (e.g., Calvo & Lundquist, 2008). Recently, Farran, Branson and King, (2011) found the evidence for a typical happy face advantage in autism. This would suggest that people with autism could have typical and atypical processing of happy faces depending on tasks. For example, some studies have reported atypical processing of happy facial expressions in people with autism (Sepeta et al., 2012), suggesting an impaired relevance network in this group, or a network for signalling social relevance that prevents individuals with this disorder automatic responding to social stimuli. However, inverted faces possibly indicate some other difficulties more related to perceptual processing of face stimuli. As mentioned earlier, processing of happy faces seems to involve both configural and featural information in faces, and it is also suggest that the happy face advantage involve interplay between emotional and perceptual factors (Farran et al., 2011). Therefore, it can be suggested that configural or featural aspects of the happy face will be more needed for recognition of this emotion depending on the task.

Findings of enhanced sad and happy faces found only in the High AQ group in the present study certainly cannot be interpreted as impairment, but only as a different way of perceptual processing of inverted facial expressions in this group. But it could be also suggested that local bias as found in people with autism and often referred to as "islet of abilities" (Baron-Cohen, 2008; Pellicano, 2011) in this group, sometimes may have some advantages of compensatory effects in the disorder. However, more research is needed to clarify positive and detrimental effects of perceptual characteristics of people with autism on their social cognition.

We also correlated the EQ with ERPs elicited by faces and houses and results indicated several important correlational patterns for AQ groups (a summary of correlational pattern is in our Results section). A correlation between the EQ and inverted stimuli was found only for the High AQ group. Furthermore, the High AQ group compared to the Low AQ group did not show any correlation between facial stimuli and the face-specific N170 component. It is difficult to interpret this finding, but several recent studies have indicated that early visual ERPs examined in responses to upright faces can be associated with social and emotional skills in typically developing individuals. For example, smaller P100 and

larger N170 amplitudes were associated with better social skills in typically developing children (Hileman, Henderson, Mundy, Newell, & Jaime, 2011). Another study (Meaux et al., 2013) found that smaller N170 amplitudes were associated with emotional expressivity, shorter N170 latency with emotional sensitivity, and lower P200 with emotional control in typical adults. We cannot directly compare our findings with those previous studies because our study differs from Meaux et al., (2013) in that that they performed correlation analysis for all facial expressions and not with separate emotions as we did and because our subjects were chosen based on their level of autistic tendency. However, our findings of higher EQ scores in the Low AQ group associated with lower central P200 amplitudes for upright neutral and fearful faces show some parallels with a previously mentioned finding of the relationship between lower P200 and emotional control (Meaux et al., 2013). Although it is difficult to say whether our results of facial expressions processing in the Low AQ group can be related to the typical population, results indicate some important differences between individuals with lower and higher autistic tendencies in their processing of facial emotional expressions.

6.5.2. Limitations and future directions

This study has several limitations. Firstly, it is possible that the choice of participants can have a strong influence on results, and a small number of participants in each group can have an effect on the power of the study. The High AQ group also had a more uneven age gap between participants, with several participants of much older age in comparison with the Low and Mid AQ groups. Previous research has indicated age differences in facial emotion processing (e.g., Hilimire, Mienaltowski, Blanchard-Fields, & Corballis, 2013; Mill, Allik, Realo, & Valk, 2009).

Secondly, the nature of the present task can influence the differentiation of emotions. Although previous research with the same methodology clearly speaks about differences in emotion processing in upright and inverted faces, it can be suggested that results are also showing activity in response to facial identity and gender, and show working memory constraints. Therefore, results of studies that use similar methodology are not easily comparable with studies that require explicit emotion recognition. Future research that would examine influence of emotional expression in inverted faces should choose a task that would show clearly that modulation is coming from emotion processing, with minimal influence of processing related to facial identity. Facial identity is clearly equally important in the task in this study, as it requires recognition of the same or different person. It has been suggested that

processing of facial identity and emotional expressions is subserved by overlapping networks (Calder & Young, 2005), including posterior perceptual regions that are modulated by facial expressions and facial identity/familiarity (e.g., Ganel, Valyear, Goshen-Gottstein, & Goodale, 2005), and frontal regions that are activated in response to socially relevant information (e.g., Adolphs, 2002b; Gobbini & Haxby et al., 2007). Nevertheless, some studies have indicated separate processing for facial identity and emotion (Haxby, Hoffman, & Gobbini, 2000). Finding our whether facial identity and facial emotion processing represent separate or interactive processes certainly may be important in autism research to shed more light on face perception deficits in this group. A recent study (Krebs et al., 2011) has found that typically developing children process facial identity and facial expressions independently, but due to an interference effect when they classify faces by emotional expressions, they process facial expressions in interaction with facial identity. In contrast, children with autism processed both facial identity and facial expression independently of each other with no an interference effect on each category. The autistic group was also slower than typically developing children group when they classified faces according to emotional expression but were equally fast in classifying faces by identity.

This study did not use eye-tracking which significantly limits explanations of findings. It has been shown in numerous studies that individuals with autism look at human faces in different ways than neurotypical individuals, with a greater degree of gaze directed at the mouth than the eyes (e.g. Klin et al., 2002). Eye tracking studies can give important information about the processing of inverted faces in this group. A recent study (Falck-Ytter, 2008) showed that although children with ASD were similar to typical children when looking at inverted faces (showing an inversion effect), children with ASD, compared to typical children, showed a stronger tendency of looking at the same features in both upright and inverted faces. Children with ASD also showed more pupil dilation when looking at inverted but not upright faces, suggesting a higher processing load in this group. Obviously, eye-tracking studies could give valuable information about strategies that people with autism and those with higher autistic tendencies use for processing facial information.

6.5.3. Conclusion

The current study found basic differences in inversion effect between individuals with lower and higher levels of autistic traits in N170 and P200, and group differences in emotion differentiation were observed in the P200 for inverted sad faces. Present findings of a weaker

inversion effect and emotion differentiation for inverted sad faces for the High AQ group can suggest that this group use more featural or analytical strategies for processing of faces. Previous studies suggested that children and adults with autism use more analytical or cognitive strategies in processing facial expressions and that neurotypical children and adults use more intuitive or automatic strategies for interpreting emotions (Dissanayake & Macintosh, 2003; Wong et al., 2008). Further research is needed to establish if the characteristics observed in individuals with autism can be also found in individuals with high autistic traits.

CHAPTER 7 -

EXPERIMENT 2:

Electrophysiological correlates of conscious and unconscious processing of emotional faces in individuals with high and low autistic traits

7.1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterised by difficulties in reciprocal social interaction and a restricted range of interests and behaviours (APA, 2000, 2013). It is generally accepted that individuals with autism have difficulties in the processing of facial expressions, and impairments were recognised particularly on more complex or negative emotions (Adolphs, Sears, & Piven, 2001; Castelli, 2005; Golan, Baron-Cohen, Hill, & Rutherford, 2007). However, deficits in emotion processing are not found in all studies (e.g., Castelli, 2005; Ozonoff, Pennington, & Rogers, 1990; Piggot et al., 2004). It is suggested that individuals with autism have problems in processing configural properties of faces because of their emphasis on featural analysis (Behrmann et al., 2006; Dawson, Webb, & McPartland, 2005). Configural processing of faces is considered to be developmentally more advanced, so deficits in configural processing may be a reflection of less expertise and less automaticity for face processing in individuals with autism. Individuals with autism may have less expertise in face processing because of their atypical social and emotional development. According to theoretical models that try to explain social and emotional impairments in autism, these impairments are results of amygdala dysfunction (Baron-Cohen et al., 2000), and several studies have indicated atypical amygdala activation in individuals with autism (Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Critchley et al., 2000). The amygdala has a central role in the processing of facial emotions in healthy populations. Although it is considered to respond primarily to threatening facial expressions, especially of fearful faces (Morris et al., 1996), is was also found to be involved in the processing of non-threatening facial expressions, such as happy and sad faces (Breiter et al., 1996; Wright, Martis, Shin, Fischer, & Rauch, 2002; Yang et al., 2002). The amygdala is considered to have an essential role in a vigilance system for rapidly alerting other brain regions to the importance of social stimuli (LeDoux, 1996; Schultz et al., 2000; Whalen, 1998). Thus, impaired amygdala in autism may lead to not finding faces socially salient, leading to reduced experience with emotional facial stimuli (Hall et al., 2007; Schultz et al., 2000). Dawson et al. (2005) have suggested that an impaired amygdala leads to abnormal social motivation that in its turn prevent orienting to socially relevant stimuli, including faces.

The amygdala can be engaged subconsciously by presenting images of facial emotions very rapidly (such that they fall outside conscious awareness) and masking them (Morris, Ohman, & Dolan, 1998; Whalen et al., 1998) or presenting them under the condition

of binocular suppression (Williams, Morris, McGlone, Abbott, & Mattingley, 2004). LeDoux (1996) suggested that fear-related responses are processed through a direct subcortical pathway that has adaptive survival value. A rapid, subcortical pathway operates simultaneously to a conscious pathway and rapidly transmits information related to biologically relevant stimuli from primary sensory cortices via the thalamus to the amygdala (LeDoux, 1996; Killgore & Yurgelun-Todd, 2004). Research support for unconscious processing of emotional faces has been found in studies of affective subliminal priming (Finkbeiner & Palermo, 2009; Jiang, Bailey, Chen, Cui, & Zhang, 2013; Monahan, Murphy, & Zajonc, 2000; Murphy & Zajonc, 1993; Nomura et al., 2004), and with cortically blind patients (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999). For example, de Gelder et al. (1999) showed that a patient with right hemianopia was able to guess the facial emotional expression at the level above the chance, even if stimuli were not seen consciously due to a damaged left primary visual cortex.

The backward masking paradigm is often used to examine non-conscious automatic responses through the subcortical pathway. In this paradigm, there is a very brief (subconscious) presentation of the face stimuli followed by a mask, which is blocking the conscious recognition of a stimulus (Esteves & Öhman, 1993).

Electrophysiological studies of non-conscious processing of facial emotional expressions that use backward-masking paradigm are able to measure temporal processing of stimuli that are not amenable to conscious awareness. However, studies do not agree about earliest effects of subliminal processing, with some studies putting it as early as the N170 (Pegna, Landis, & Khatab, 2008), an early visual ERP component that usually peaks between 140-200 ms. Another study found the first appearance of both subliminal and supraliminal fearful faces between 140 ms and 180 ms (Kiss & Eimer, 2008; Eimer et al., 2008), but as the effect was found on anterior electrodes it differs from the N170, which usually peaks over posterior sites. However, some studies (Liddell et al., 2004) found that subliminal emotional faces produced a later response on the N200 component at fronto-central electrodes. Differences in findings can be explained by methodological variety. Most of those studies differed on various methodological points, particularly duration of subliminal stimulus presentation (varying from 8 ms to 33 ms), and differences in mask, with many of them using neutral faces as a mask. Following Kiss and Eimer's (2008) suggestion that using neutral faces as a mask can influence stimulus probability, particularly when using neutral faces

along emotional facial expressions, in the present study an abstract pattern will be used for masking instead of neutral faces.

Several fMRI studies investigated subliminal processing of emotional and social information in individuals with autism by using a backward masking paradigm. While some of them found deficits in subliminal processing in this disorder (Hall et al., 2007; Kamio, Wolf, & Fein, 2006; Kleinhans et al., 2011), some studies did not find differences between subjects with autism and healthy controls in the amygdala activation during sub-threshold presentation of facial expressions (Hall et al., 2010). However, atypical automatic facial mimicry (EMG) to backwardly masked briefly presented happy and angry facial expressions was found in adults with ASD (Mathersul, McDonald, & Rushby, 2013), and impaired recognition of briefly presented, but not backwardly masked, happy and angry faces was also found in young adults with ASD (Clark, Winkielman, & McIntosh, 2008).

The aim of the present study is to assess processing of subliminal and supraliminal facial expressions by investigating individual differences in autistic traits using the Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). The AQ is a self-administered, 50-item questionnaire measure of autistic traits. We expected to find group differences between participants with low and high AQ predominantly in emotion differentiation in subliminal condition. The present study also predicted that subliminal face processing would be mostly seen on earlier components, particularly N200 and P300a (early P300). Lidell et al. (2004) suggested that subliminal and supraliminal emotion processing could be distinguished with the N200/early P300 components representing "orienting" and N400/late P300 "event integration", based on the Halgren and Marinkovic (1995) model of emotion processing. As some other ERP studies found earlier discrimination of facial expressions as representing subliminal processing (e.g., Pegna et al., 2008; Eimer & Kiss, 2008), we also include the earlier component, the N170. The N170 is considered to be a face-specific component reflecting structural encoding of faces (Bentin et al., 1996; Itier & Taylor, 2004a). Both P100 and N170 represent the earliest stages of face processing and there is some evidence for atypical responses on those components in children and adults with autism compared to those without autism (e.g., Hileman et al. 2011; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; O'Connor et al., 2005, 2007). In the present study, fearful and happy facial expressions will be included in order to examine subliminal processing of both positive and negative facial expressions. The majority of studies that investigated temporal neural processing of subliminal facial expressions by using a backward masking paradigm

mostly examined threatening faces, like fear and anger (Pegna, Landis, & Khateb, 2008; Suslow et al., 2006). Only a few studies (e.g. Balconi & Mazza, 2009; Smith, 2009) examined other facial expressions, such as disgust (Lawrence et al., 2007), happiness (e.g., Killgore & Yurgelun-Todd, 2004; Whalen et al., 1998) and surprise (Duan, Dai, Gong, & Chen, 2010). Besides looking at individual differences in autistics traits in subliminal and supraliminal emotional face processing, an additional goal of the present study will be to look at the earliest appearance of emotional effects in subliminal conditions regardless of autistic tendency, following the distinction between "orienting" and "event integration" as proposed by Lidell et al. (2004).

7.2. Methodology

7.2.1. Participants

Thirty-five participants (19 females) completed an online version of the AQ, EQ and SQ scales, and based on their AQ scores were selected to participate in the EEG study. Demographic information of participants was also collected online. All participants had normal or corrected-to-normal vision, with no neurological impairment. All participant were right handed. They signed informed consent forms to participate and the ethics committee of the Swinburne University of Technology, Melbourne, Australia, approved all experimental procedures. The **table 7-1** shows participans' characteristics.

Table 7-1. Participants' Characteristics

	AQ											
	Low (n = 14; 6 females)				**Mid** (n = 9; 6 females)				**High** (n = 12; 7 females)			
	M	SD	Min	Max	M	SD	Min	Max	M	SD	Min	Max
Age	28.57	6.15	19	43	24.11	4.62	18	33	30.58	10.3	19	55
AQ	7.86	2.8	2	11	16	2.45	12	19	25.17	5.57	21	39
EQ	53.50	9.72	41	70	48.22	16.25	19	65	35.67	13.01	10	59
Raven's	21.64	5.03	12	31	20.67	4.03	15	28	19.92	6.82	10	31

7.2.2. Measures

All participants completed online questionnaires: the Autism Spectrum quotient (AQ), the Empathy Quotient (EQ), and the Systemizing Quotient (SQ) questionnaires. However, not all participants completed the SQ, so results are excluded from this analysis. Participants also completed the Advanced Raven's Progressive Matrices before or after EEG testing.

The Autism Spectrum Quotient (AQ) is a self-administered questionnaire that consists of 50 questions, devised to quantitatively measure the degree to which a person with normal intelligence has autistic traits (Baron-Cohen et al., 2001; Woodbury-Smith et al., 2005). Participants respond using a 4-point rating scale, from "definitely agree" to "definitely disagree".

The Empathy Quotient (EQ) is a self-administered questionnaire that consists of 40 questions assessing empathy (Baron-Cohen & Wheelwright, 2004). Lower scores on the EQ have been found in adults with autism (Baron-Cohen & Wheelwright, 2004) and in neurotypical men compared to women (Baron-Cohen & Wheelwright, 2004; Lawrence et al., 2004). The EQ was found to have high test-retest reliability (Lawrence et al., 2004). A recent study (Sucksmith et al., 2013) found deficits on the EQ in fathers of a child with autism, suggesting the importance of this questionnaire for the broad autism phenotype research.

The Raven's Advanced Progressive Matrices test is a standardised intelligence test measuring mostly the nonverbal domain. It consists of visually presented geometric figures where one part is missing and a correct missing part must be selected from offered answers to complete the designs (Raven, 2000; Kunda, McGreggor, & Goel, 2009). Because of its high correlation with other multi-domain intelligence tests, this test occupies an important place within psychometric testing as a test of general cognitive ability and intelligence. It is developed to measure two components of general cognitive ability - educative and replicative ability (Ravens, 2000). Educative ability refers to an ability to extract schematic information from a complex situation and replicative ability to absorb, recall and reproduce information. A positive side of this test is the easiness of administration and interpretation (Raven, 2000). In the current study, we used the Raven's test with a time limit of 20 minutes.

7.2.3. Stimuli

The stimuli consisted of greyscale photographs of the faces of 6 male and 6 female models, each of them with both open and closed mouths. The models' faces depicted neutral,

fearful and happy expressions and were cropped to remove external features. The facial images were taken from the NimStim set (Tottenham et al., 2009), and a mask was created by phase scrambling images of faces by using MatLab.

7. 2.4. Experimental Procedure

Subjects sat in an electrically shielded, dimly-lit and sound-attenuated room in front of a computer screen. The experiment was programmed with E-Prime 1.2 (Psychology Software Tools, Inc., Pittsburgh, PA). Stimuli were presented in 8 blocks of 138 trials, each block consisting of a randomised presentation of both subliminal and supraliminal faces. Block order was counterbalanced across participants. Before starting the experimental procedure, participants were given a practice run. At the beginning of the experiment, a white fixation cross appeared in the middle of the screen and lasted for 700 ms. Shortly thereafter, a picture of a face stimulus was displayed for duration of 16 ms (subliminal threshold condition) or 166 ms (supraliminal threshold condition), immediately followed by the mask for 284 ms for subliminal presentation or 134 ms for supraliminal presentation, in order to keep the presentation constant for 150 ms (**Figure 7-1**).

Figure 7-1: Experimental procedure
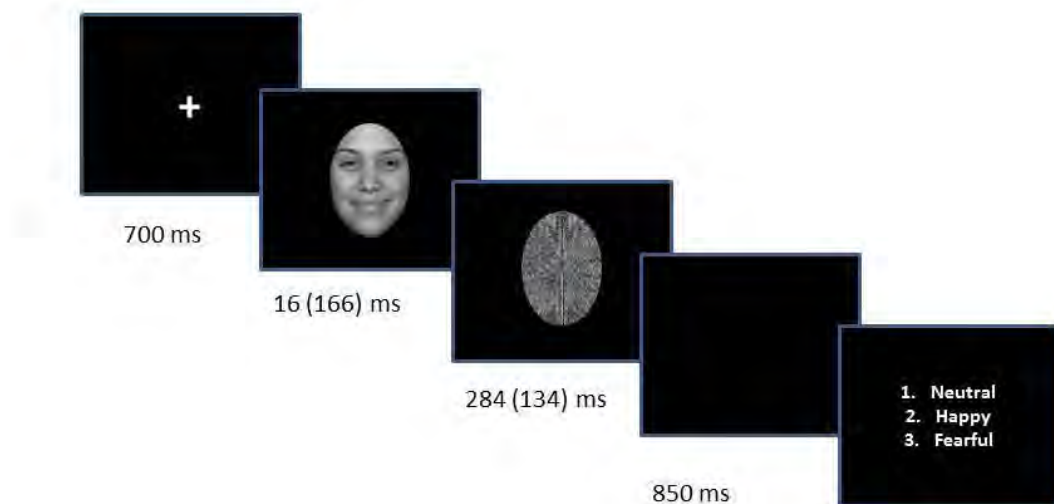
At the end of each trial, a question appeared on the screen asking for explicit emotion recognition, and a new trial started only after participants answered. Participants were asked

to guess the very briefly presented stimuli. This task gave equal importance to all facial expressions in both conditions. There was equal number of trials in each condition for each facial expression (120 trials for each facial expression, for each condition). Participants were asked to press the answer with the right hand.

7.2.5. ERP recording and analysis

7.2.5.1. Electrophysiological recording

EEG activity was recorded using a Geodesic Sensor Net with 64 electrodes, with the vertex (Cz) electrode used as a reference. The amplification was set at 1000. EEG signals were filtered through a 0.05 Hz high-pass filter and 70 Hz low-pass filter with the recording rate of 500 Hz. Electrode impedances was kept below 5 kΩ.

Recordings were re-referenced to the average reference as computed from all scalp electrodes (for component: N170), and to the average of mastoids (for N200, P300a, P300b, N400).

EOG was recorded from two electrodes placed at the external canthi of both eyes and from two electrodes on the infraorbital and supraorbital areas of the left eye to monitor for eye movements and blinks. The raw data were segmented into epochs using a window of 200 ms pre-stimulus to 800 ms post-stimulus. Trials in which amplitude exceeded ±100 μV were automatically rejected, which eliminated eye blinks and other movements. In addition, all epochs were visually inspected and epochs containing eye movements and other artefacts were removed. Only epochs containing at least 50 % of trials were taken for further analysis. Bad channels were corrected by individual channel-interpolation (interpolating channel by using nearby channel data). ERPs were averaged separately for each stimulus category (each emotion was averaged for subliminal and supraliminal threshold conditions), baseline corrected and low-pass filtered at 30 Hz (24dB/octave).

7.2.5.2. ERP analyses

The time windows for ERP components were selected based on a review of the literature and examination of grand averages. The N170 ERP was examined at the lateral occipito-temporal sites P7 and P8, and N200, P300a, P300b and N400 at midline electrodes Fz, Cz and Pz. The peak amplitudes and latencies were measured in the following latency windows: N170 (140-220 ms), N200 (180-300 ms), P300a (240-350 ms), P300b (400-700

ms) and N400 (300-500 ms). ERP amplitude and latency were analysed with repeated-measures ANOVA using the AQ Group as the between-subject factor, with emotion (neutral, happy, fearful), condition (subliminal, supraliminal), and hemisphere (left and right, only for N170)/electrode (Fz, Cz, Pz) as within-subject factors.

Degrees of freedom were adjusted with the Greenhouse-Geisser epsilon for factors with greater than two levels. Paired-samples t-test, one-way ANOVA and Pearson correlations were performed to supplement the ERP findings. An alpha level of $p < 0.05$ was used unless otherwise noted.

7.3. Results

7.3.1. Behavioural

Across all groups and facial expressions, the analysis revealed an accuracy rate of 57.19% in subliminal and 92.68% rate in supraliminal conditions. Across all subjects, in the subliminal condition, the highest accuracy rate was found for neutral (66.90%), followed by fearful (62.67%), with lowest accuracy rate for happy faces (41.67%). In the supraliminal condition, the highest accuracy rate was found for neutral faces (94.21%), followed by happy (91.90%) and fearful (91. 86%). Overall, the paired t-test showed significantly lower accuracy rates for all subliminal when compared to supraliminal emotions (all $p = 0.0001$), with no significan differences between subliminal and supraliminal emotions for reaction times (RTs).

Across all groups, accuracy and reaction times (RTs) were measured by using repeated measures ANOVA for each condition. Significant effect of emotion in subliminal condition ($F(2,64) = 12.07$, $p = 0.0001$) was found, with happy faces showing lower accuracy rates compared to neutral and fearful expressions (both comparisons, $p = 0.0001$). Although there was not statistically significan emotion effect in supraliminal condition ($F(1,41) = 2.61$, $p = 0.1$), there were higher accuracy rates for neutral compared to happy faces ($p = 0.01$). (**Figure 7-5**; **Figure 7-6**).

Nothing significant was found for RTs. No significant group differences were found neither for accuracy rates nor for RTs (**Figures 7-2, 7-3, 7-4, 7-5).**

Figure 7-2 Mean accuracy rates for subliminal faces.

Figure 7-3. Mean accuracy rates for supraliminal faces.
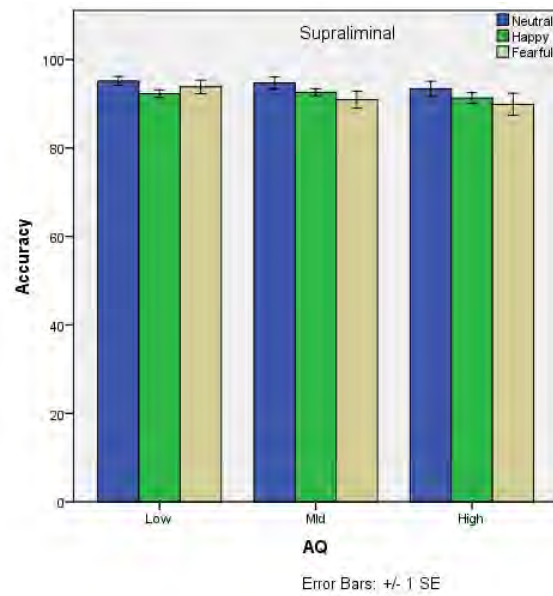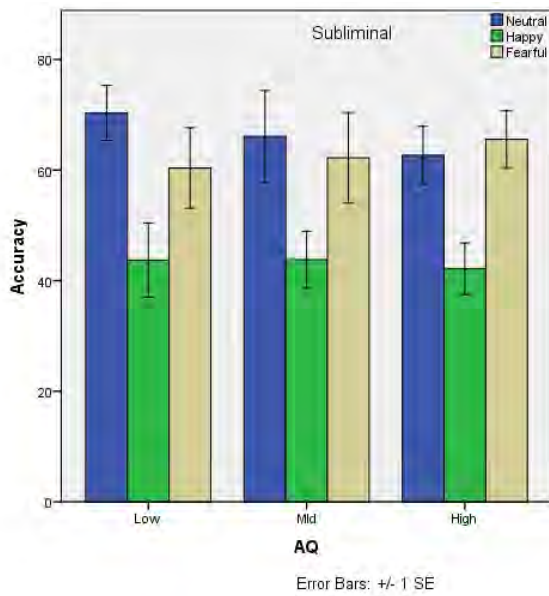
Figure 7-4. Mean RTs for subliminal faces
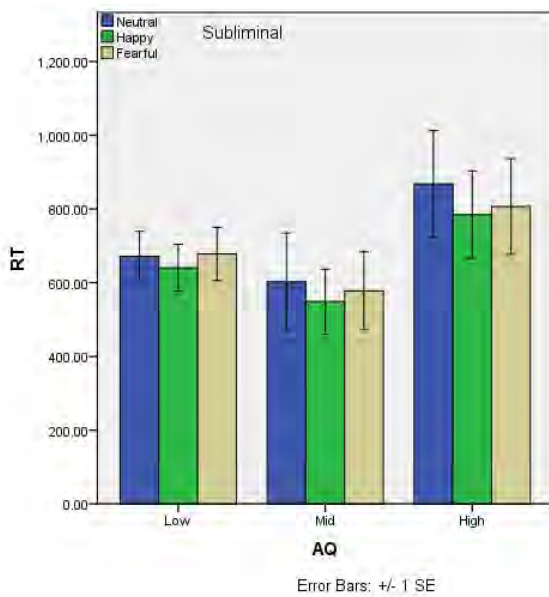
Figure 7-5. Mean RTs for supraliminal faces
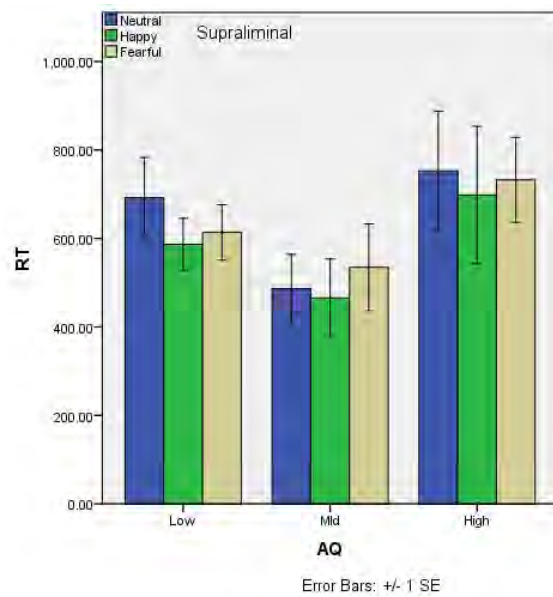
A one-way ANOVA was used to compare EQ scores between different groups and the analysis revealed significant group differences (F = 6.79, p = 0.003), with higher scores in the Low AQ compared with the High AQ group (p = 0.003, mean difference = 18.07), and marginally higher scores in the Mid AQ compared to the High AQ group (p = 0.06, mean difference = 14.22). Significant group differences were found for the SQ scores (F = 3.48, p = 0.05), showing marginally higher SQ scores for the Mid AQ group when compared to the Low AQ group (p = 0.07, mean difference = 28.8), although the Low AQ group showed a

tendency to have lower SQ scores when compared to both High and Mid AQ groups. No significant group differences were found for Raven's scores (p = 0.41). **Figure 7-6** shows mean EQ scores for each group.

Pearson correlation analysis showed negative correlation between AQ and EQ scores (r = -0.7, p = 0.001) (**Figure 7-7**). Inverse correlation between the EQ and the AQ is in agreement with previous studies (Baron-Cohen & Wheelwright, 2004). Raven's scores did not correlate with any of measures.

Figure 7-6.

Mean EQ score by group. Higher EQ scores were found for the Low AQ compared to the High AQ group, and marginally for the Mid AQ compared to the High AQ group.

Error Bars: +/- 1 SE
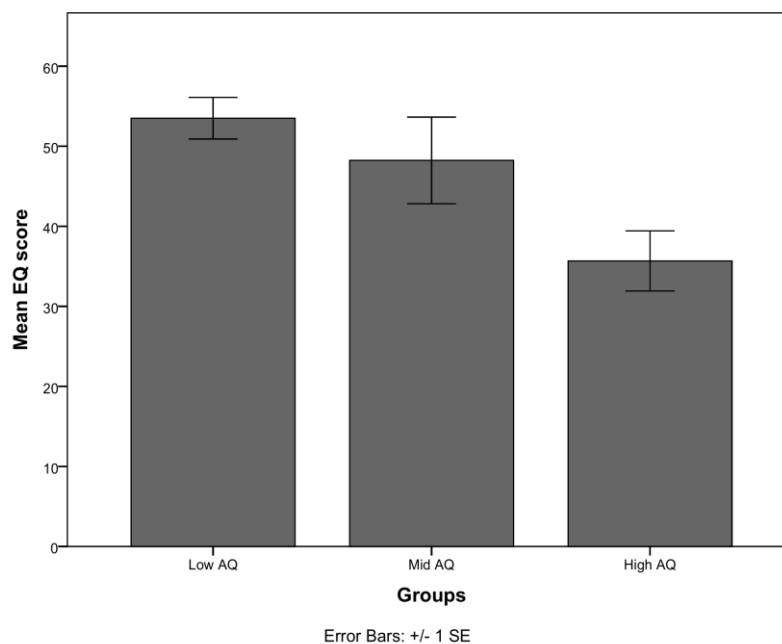
Figure 7-7. Pearson correlation between AQ and the EQ scores. There is a negative correlation between AQ and EQ scores.
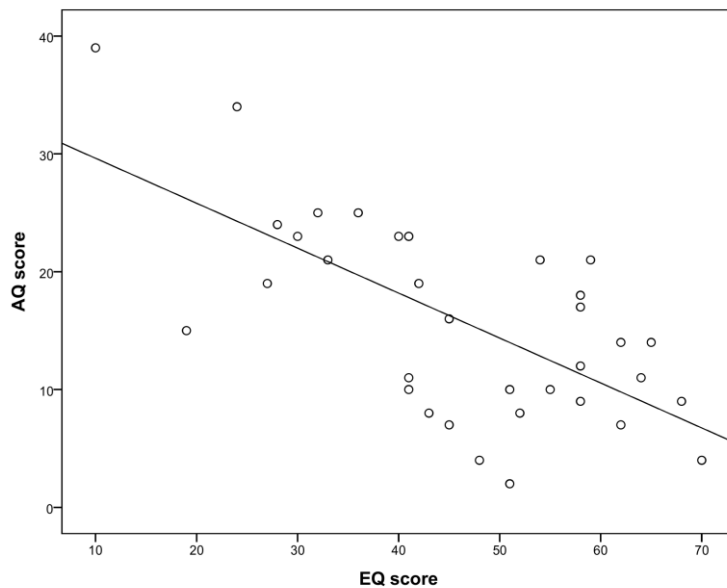
7.3.2. ERP Results

Results are first shown for the N70 component and then for other components (N200, P300a, P300b and N400). Analysis focused on finding significant condition effect across all facial expressions and emotion effect in each condition. Results are shown for all participants (groups) and for group comparisons. Most of results show condition effect across all participants and major emotion effect showing group differences is found on the N200 for subliminal faces. Grand average ERPs indicating condition effect across all participants for major ERPs examined on midline electrodes are shown in **Figure 7-11**.

7.3.2.1. Across all participants

N170 Amplitude

Analysis of the N170 amplitude across all AQ groups and both conditions showed significant effect of hemisphere ($F(1,32) = 8.04$, $p = 0.01$). Larger N170 amplitude was found in the right hemisphere for both subliminal and supraliminal conditions (both conditions, $p = 0.01$). Although no significant hemisphere x AQ group interaction was found, significant effect of hemisphere, with significantly larger N170 amplitude in the right hemisphere, was

found only for the Low AQ group (F(1,13) = 13.87, p = 0.003), both across both conditions and for each of them (both p = 0.01).

Further analysis revealed a marginally significant effect of emotion x condition interaction (F(2,48) = 2.68, p = 0.09) in the left hemisphere. The additional ANOVA performed in the left hemisphere revealed a significant effect of emotion (F(2,51) = 3.09, p = 0.07) in the subliminal condition, with marginally larger amplitudes for fearful than happy faces (p = 0.08).

N170 Latency

Across AQ groups, analysis for N170 latency revealed significantly shorter supraliminal than subliminal latencies (condition effect) (F(1,32) = 10.99, p = 0.002). No significant emotion effect was found for N170 latency.

N200 Amplitude

Across all AQ groups analysis revealed the main effects of the condition, with larger N200 amplitude for the subliminal than supraliminal condition at all sites (F(1,32) = 8.44, p = 0.01) .

Across all groups, analysis for parietal regions (Pz) revealed a significant effect of emotion in supraliminal condition (F(2,64) = 5.01, p = 0.01), with larger amplitudes to happy than fearful faces (p = 0.003).

N200 Latency

Across all AQ groups a main effect of condition was found at all sites (F(1,39) = 36.08, p = 0.001) (frontal: F(1,35) = 31.9, p = 0.001; central: F = 22.28, p = 0.001; parietal: F = 21.53, p = 0.001), with shorter latencies for subliminal than supraliminal stimuli. All AQ groups showed shorter N200 latencies for the subliminal than supraliminal condition at all sites (p < 0.05 for all groups).

P300a Latency

A main effect of condition was found for P300a latencies across all groups and sites (F(1,32) = 23.04, p = 0.0001), with shorter latencies in supraliminal than subliminal condition. No group differences were found.

Across all groups and conditions, analysis of frontal P300a latencies revealed a main effect of emotion x condition interaction ($F_{(2,64)} = 5.02$, $p = 0.01$). Further analysis showed a main effect of emotion in the *supraliminal* condition at the frontal site ($F_{(2,50)} = 5.45$, $p = 0.01$), with longer latencies for neutral compared to fearful ($p = 0.04$) and happy ($p = 0.06$) faces.

P300b amplitude & latency

Across all AQ groups, the P300b amplitudes and P300b latencies revealed a main effect of condition at all sites (all sites, $p < 0.05$), showing larger P300b amplitudes ($F_{(1,32)} = 19.16$, $p = 0.001$) and shorter P300b latencies ($F_{(1,32)} = 38.75$, $p = 0.0001$) in the supraliminal than subliminal condition.

7. 3.2.2. Group differences

N200 Amplitude: Condition effect

A marginally significan group difference in condition (AQ x condition interaction) for the N200 amplitude were found at the frontal (Fz) ($F_{(2,32)} = 3.06$, $p = 0.06$) site. Further analysis revealed larger N200 amplitudes for the subliminal condition for the High AQ ($F_{(1,11)} = 5.36$, $p = 0.04$) and the Mid AQ ($F_{(1,8)} = 6.8$, $p = 0.03$) groups. The Low AQ group did not show a significant effect of condition.

N200 Amplitude: Emotion effect

Some group differences in emotion effects were found at the frontal (Fz) N200 amplitude for subliminally presented faces, although with no reaching statistical significance (emotion x AQ interaction) ($F_{(4,64)} = 2.18$, $p = 0.07$). A further comparison between Low and High AQ groups (excluding the Mid AQ) showed significant emotion x AQ interaction ($F_{(2,48)} = 3.58$, $p = 0.4$). There was a main emotion effect ($F_{(2,26)} = 3.39$, $p = 0.05$) for the Low AQ group, showing larger N200 amplitude for happy (-5.41) than neutral (-4.46) faces ($p = 0.01$) (**Figure 7-8; 7-9**). The High AQ group showed a tendency to have lower amplitudes to emotional facial expressions (happy and fearful faces) compared to neutral faces at all sites in the subliminal condition, although this effect did not reach statistical significance.

Figure 7-8. Grand-average ERP waveforms of N200 in response to subliminal facial expresssions for Low AQ (A) and High AQ (B) groups. The Low AQ group shows larger amplitudes for happy than neutral faces. The High AQ group does not have emotional differentiation. Inserted image shows position of Fz electrode.
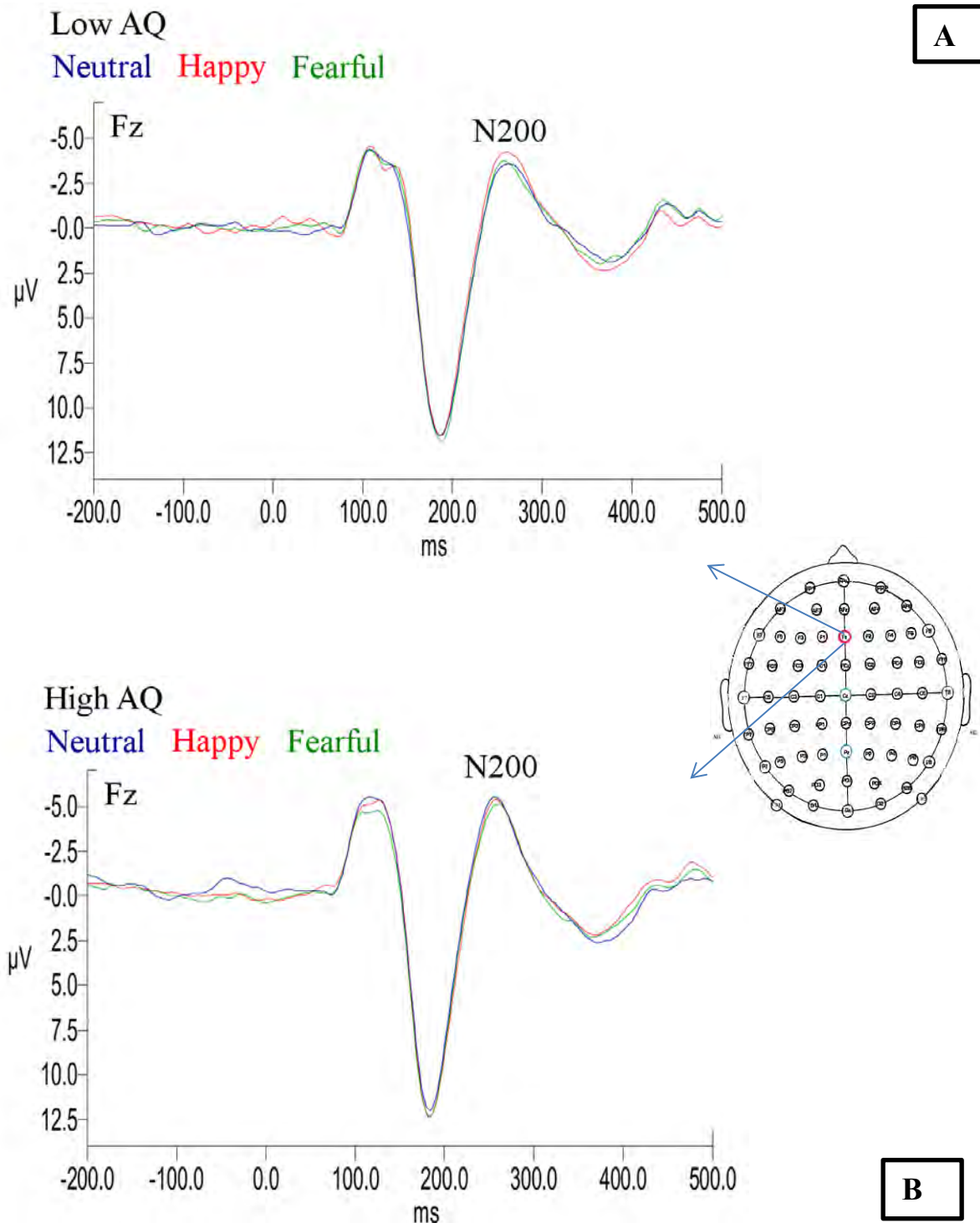
Figure 7-9. Topographic maps for subliminal faces. Topographic maps are indicating the cortical activities during 180-300 ms (N200) for subliminally presented fearful minus neutral and happy minus neutral faces in Low and High AQ groups. An increased negativity (blue colour) is found for the Low AQ group for happy minus neutral faces.
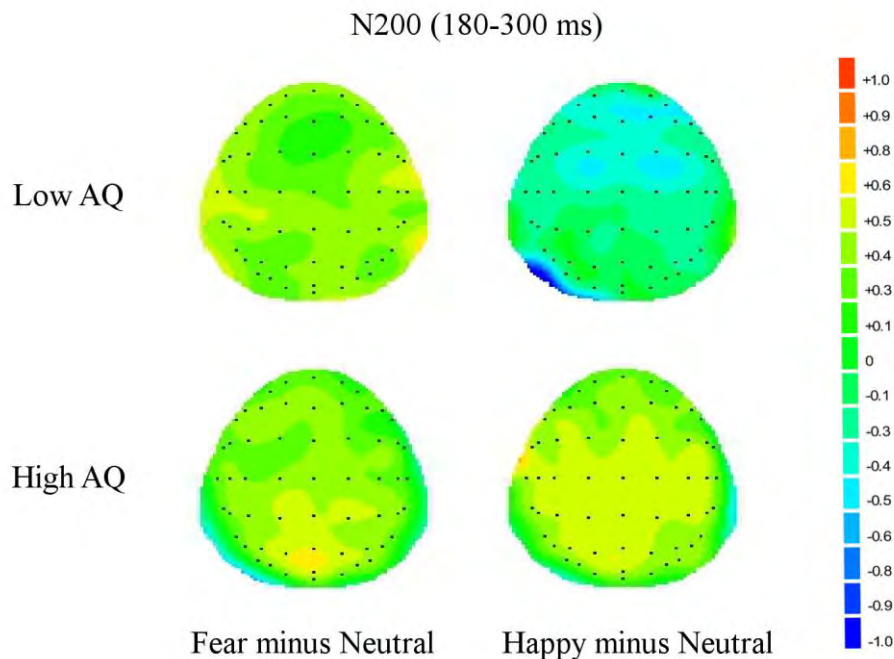
P300a Latency

A between subjects effect was found for the parietal P300a latencies for supraliminal faces $(F(1,32) = 4.53, p = 0.02)$. Further analysis revealed shorter P300a latencies for supraliminal faces in the High AQ compared with Mid AQ group $(p = 0.02)$.

P300b Latency

A marginally significant group difference in emotion processing (emotion x AQ interaction) was found in the subliminal condition at the frontal site (Fz) $(F(4,64) = 2.32, p = 0.07)$. Significant emotion effect for subliminal faces was found for the Low AQ on **frontal P3b latencies** $(F(2,26) = 3.99, p = 0.03)$, revealing shorter latencies for happy than fearful faces $(p = 0.04)$. No emotion effect was found for other AQ groups (**Figure 7-10**).

N400 Latency

Analysis of the N400 latencies revealed a marginally significant condition x AQ interaction at the frontal site (Fz) $(F(2,32) = 2.91, p = 0.07)$. Separate ANOVAs for each

group found condition effects only in the Low AQ group (F(1,13) = 12.43, p = 0.004), with shorter latencies in the supraliminal than subliminal condition. No condition differences were found for other groups.
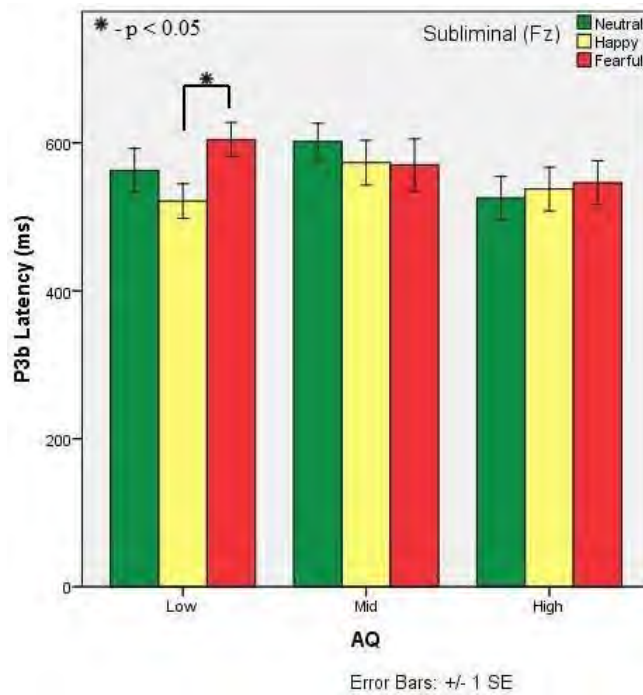
Figure 7-10: P300b latency for subliminal faces (Fz). There are shorter P300b latencies for happy compared to fearful faces for the Low AQ group, with no emotion effects in other groups.

7.3.2.3. The one-way ANOVA

Analysis of the one-way ANOVA revealed larger **N200** amplitudes for the Mid than Low AQ groups for subliminal fearful faces (at Fz, F = 3.09, p = 0.06), and longer N200 latency for supraliminal neutral faces for the Low compared to the Mid AQ group (at Fz, F = 3.45, p = 0.04).

Furthermore**,** shorter **P300a** latencies (at Pz) were found for supraliminal neutral faces in the High AQ compared to Mid AQ (F = 4.01, p = 0.03).

The one-way ANOVA revealed longer **P300b** latencies for supraliminal happy faces (Fz) for the Mid AQ when compared with the Low AQ (p = 0.04) and High AQ (p = 0.03) groups (F = 4.41, p = 0.02). Larger P300b amplitude (Cz) for neutral and fearful subliminal faces was found for the Mid AQ compared with the Low AQ group (neutral: F = 4.14, p = 0.02; fearful: F = 3.31, p = 0.05).

Figure 7-11. Grand-average ERP waveforms of N200, N400, P300a and P300b in response to supraliminal and subliminal faces. ERPs are indicating activities at Fz (A), Cz (B) and Pz (C) electrodes, collapsed across all participants and all facial expressions.

(A)

(B)

(C)
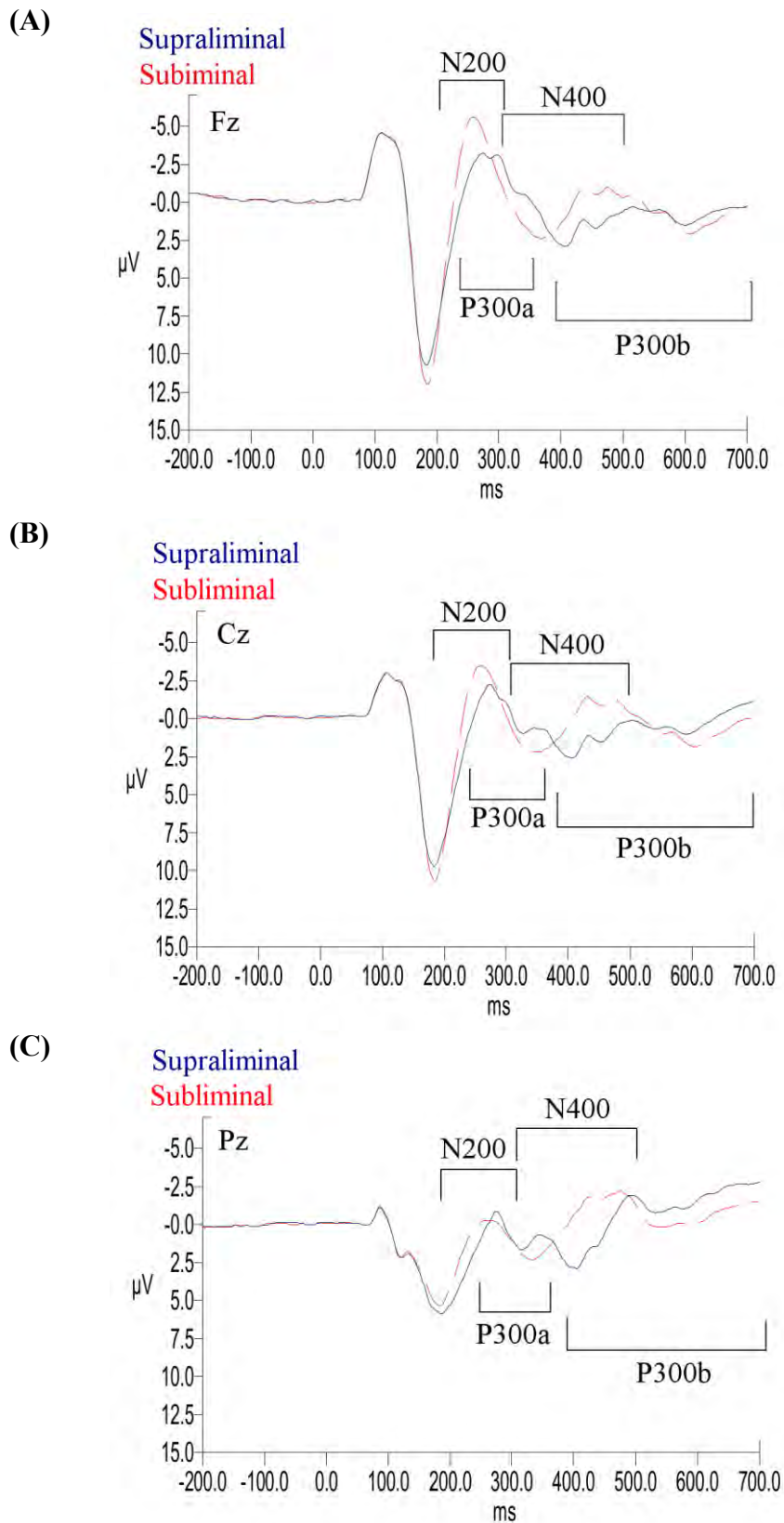
7.3.2.4. Correlations (across all groups):

AQ score correlations

Across all groups, higher AQ scores were related to longer P300b latencies for subliminal neutral (Pz) (r = 0.34, p = 0.04) and happy (Cz) (r = 0.33, p = 0.05) faces. Across all groups, a positive correlation was found between the AQ score and N400 latencies for supraliminal happy (r = 0.33; p = 0.04) and fearful (r = 0.38, p = 0.02) faces, and the N400 amplitude for supraliminal fearful faces (r = 0.33; p = 0.05); all effects for N400 component were found at the frontal site (Fz). These results show that at earlier components, AQ scores were correlated with subliminal faces, but at the later, the N400 component, with supraliminal faces.

EQ score correlations

The EQ score correlated positively with N170 latency for subliminal happy faces (P7). Higher EQ scores were related to shorter P300b latencies for subliminal neutral faces (Cz) (r = -0.37, p = 0.02). A negative correlation was found between the EQ score and N400 amplitudes for supraliminal fearful faces (all electrodes) (Fz: r = -0.33, p = 0.04; Cz: r = -0.33, p = 0.05; Pz: r = -0.34, p = 0.04).

7.3.2.5. Summary of findings for condition effect

Across all groups, larger N200 amplitudes (Fz, Cz) and shorter latencies (all sites) were found for the subliminal than supraliminal condition. Results also showed shorter P300a latencies for the supraliminal condition. Larger P300b amplitudes and shorter latencies for the supraliminal than subliminal condition were also found across all groups.

Group differences (condition x AQ interaction) were significant for the N200 amplitudes, with larger N200 for the subliminal condition (Fz, Cz) in the High and Mid AQ groups, with no condition effect in the Low AQ group. N400 latencies showed shorter N400 latencies for the supraliminal than subliminal condition in the Low AQ group, with no condition effect in the High AQ group.

7.3.2.6. Discussion

The main goal of this study was to examine subliminal facial expression processing in individuals with higher and lower autistic tendency by using neutral, positive (happy) and

negative (fearful) facial expressions. Partial support was found for the main hypothesis of finding group differences between individuals with lower and higher autistic traits in emotion effect under subliminal conditions. However, this effect was found only for subliminally presented happy faces and mostly at the frontal site, showing emotional differentiation in the Low AQ group, but not in the High AQ group.

In the present study, there were not significant effect of emotion on the N170 ERP component. Pegna et al. (2008) found emotion differentiation in this component in both subliminal and supraliminal conditions, with greater amplitudes for fearful faces, particularly over the right hemisphere electrodes. However, not all studies found a significant effect of emotional facial expressions at the N170 (e.g., Kiss & Eimer, 2008), probably because of the differences in methodology, particularly the use of reference electrodes. In the present study, average references were used, and similar patterns of results of emotion differentiation in the subliminal condition was observed in another study that used average references (Pegna et al., 2008).

The most important group differences in emotion differentiation were found for subliminal faces.Important differences were found at the N200 component, with enhanced N200 amplitude for subliminal happy faces at the frontal N200 for the Low AQ group only. Another emotion effect that was found in the Low AQ group and not in other groups was at P300b, showing faster processing of happy compared to fearful faces in the subliminal condition.

It is interesting that in the present study group differences in effects of emotion on the N200 component were found only in the subliminal condition (at Fz), whereas across all AQ groups emotions modulated activity in the supraliminal condition (at Pz), with decreased amplitudes for fearful compared to neutral faces. Discrepancies in emotion processing at the subliminal and supraliminal level at this component could be explained by different results regarding the onset of emotional discrimination in the subliminal condition found in previous studies. For example, Lidell et al. (2004) and Kiss and Eimer (2008) found differences between expressions only in the subliminal condition at the N200, whereas Pegna et al. (2008) found differences between expressions only in the supraliminal condition. Some other studies found modulations in the supraliminal condition in this component by using masked line drawings rather than face stimuli (e.g., Wilenius-Emet et al., 2004; Koivisto et al., 2006). Pegna et al. (2008) proposed that this component represents early responding to conscious

emotional information, whereas Liddell et al. (2004) considered the N200 to represent an automatic, non-conscious attention-orienting response to emotionally relevant stimuli. This component is also considered to be a "semiautomatic" component that may represent the final phase of the automatic attention-related neural mechanism (Carretié et al., 2004).

Discrepancies between various studies that examined subliminal processing of facial emotional stimuli, including the present study, may be explained by possible residual awareness in participants. The duration of 16 ms adopted for the subliminal presentation in this study was among the shortest durations used in other studies, which was considered a reliable predictor of non-aware condition. Some studies used a longer duration of about 33 ms, which is also considered to represent rapid, non-aware condition, consistent with a subcortical route to the amygdala (LeDoux, 1996; Liddell et al., 2005; Morris, Ohman, & Dolan, 1999; Pasley, Mayes, & Schultz, 2004). Also, personal reports of participants at the end of each block in the present study revealed that some of them were able to notice eyes or mouths in the subliminal condition, although all of them said that they did not see whole faces or facial expressions in the subliminal condition. It can be suggested that in the present study, partial conscious perception was present. In general anaesthesia, for example, there is an important unresolved question about the possibility of partial conscious perception (Daunderer & Schwender, 2004). It can be further proposed that in the present study there are differences between groups with high and low autistic tendency in sensitivity to visual thresholds. This proposal is based on findings of group differences for threshold condition effect, although no significant group differences were found for accuracy and reaction times. Individual differences in subliminal face processing were observed in some other studies. For example, it was found that N200 and P200 amplitudes varied according to attachment-orientation (Zhang et al., 2008). However, it is not clear whether individual differences between groups could be explained by visual sensitivity in the subliminal condition. It can be suggested that any further study on subcortical face processing in individuals with high and low autistic traits should carefully examine group differences for visual threshold recognition of stimuli, and possibly look at group differences in this threshold of awareness.

The importance of taking into consideration individual differences in visual awareness of stimuli can be found in some previous studies that examined subliminal processing of facial expressions. Eimer, Kiss and Holmes (2008) measured ERP responses to fearful faces in a backward masking paradigm where fearful or neutral faces were presented for 17, 50, or 200 ms. In order to find out whether ERP emotional effects are associated with subjective

perceptual awareness, they examined ERPs separately on those trials where participants correctly recognised fearful faces (fearful-detected) and on those trials where participants failed to correctly recognise fearful faces (fearful-undetected trials). The main idea was that if ERP emotional effects were triggered independently of subjective awareness, they should be seen on both trials. Their results for a short duration condition lasting 17 ms (closer to the duration for the subliminal condition in our study), revealed that ERP effects for fearful faces was closely associated with subjective awareness. However, in another study, Williams et al. (2004) found that thresholds for non-conscious detection of fearful faces to be 10 ms, and for non-conscious discrimination to be 30 ms, compared to conscious perception of 170 ms. They found that both non-conscious detection and discrimination of fearful faces showed an enhanced N200 component, and non-conscious detected fearful faces showed a shorter P100 component, with conscious fearful faces enhancing the N400 component. The authors proposed that the N200 reflects detection of faces (Williams et al., 2004). It is interesting that a recent behavioural study showed that emotion detection can happen for backwardly masked faces presented for only 10 ms, and that emotion detection is best when a face has a happy expression when compared to anger and fearful facial expressions (Sweeney, Suzuki, Grabowecky, & Paller, 2013). If we consider that some of those findings could be used as an explanation for the results of the present study, we could suggest that our results on the N200 amplitude mainly represent early detection of emotional faces in the subliminal condition, rather than discrimination of emotional expressions, and that happy faces have a primary role in the detection of salient stimuli.

Attention to backwardly masked facial expressions can also influence ERP modulations and the onset of subliminal processing. Several studies indicated that ERP emotional differentiation is influenced by participants' attention (Eimer et al., 2003; Holmes et al., 2003). Pessoa, Japee, Sturman and Ungerleider (2006) showed in their fMRI study that amygdala activation for fearful faces was modulated by participants' subjective awareness. Pegna et al. (2008) suggested that attending to masked facial expressions may be necessary for earlier ERP effects in the subliminal condition. For example, Liddell et al. (2004) used a task that required passive viewing of faces, and the onset of subliminal processing was observed at the N200 components at fronto-central electrodes. Pegna et al. (2008) used a task that required discrimination between fearful and non-fearful faces, and the earliest differences in ERP responses were observed in the N170 component.

Previous studies indicated that selective attention can also affect the amygdala responses to happy and fearful facial expressions. For example, Williams, McGlone, Abbott and Mattingleya (2005) examined activation of the amygdala in the response to happy and fearful faces in tasks that required participants to attend to faces or to houses. They found greater activity in the amygdala for happy faces in the condition that required participants to attend to the face than in the condition that required attending to the house. In contrast, they found greater amygdala activity for fearful faces in the attend-house than in the attend-face condition. With regard to the role of spatial attention on temporal processing of backward masked facial expressions (fearful faces), Carlson and Reinke (2010) used a dot-probe task to show that masked fearful face-elicited spatial attention enhances the contralateral occipito-temporal N170. In this study, face cues were presented for duration of 33 ms, suggesting that spatial attention to faces facilitates the early stage of subliminal face processing at the N170 component. Another study supported enhanced N170 by both subliminally (16 ms) and supraliminal (centrally) presented fearful faces even when faces are not attended to (Pegna et al., 2011). Based on these findings that suggest the importance of attention, it would be necessary to examine subliminal face processing in people with higher and lower autistic traits on a passive viewing task, or a task where emotion will be processed implicitly, to see if differences between groups could be observed for fearful subliminal faces, something that was not found in the present study by using an explicit emotion processing task.

In addition, it is possibly that behavioural and ERP results of this study may be influenced by pre-stimulus oscillatory activity, something that was not investigated in this study. Some recent studies have showed an increasing interest in the role of oscillatory activity in shaping visual perception. For example, Busch, Dubois and VanRullen (2009) found that visual stimuli near threshold of visibility were dependent of appearance of low alpha and theta bands immediately before stimulus onset.

It is difficult to explain group differences of shorter latencies at the frontal P300b for happy compared to fearful faces in the Low AQ but not in the Mid and High AQ groups, which were found in the present study in the subliminal condition. In the present study, the P300b component was seen to have enhanced amplitudes for the supraliminal threshold condition across all groups. The P300b is considered to represent a stage of event integration at a conscious level (Lidell et al., 2004). However, earlier studies indicated that, under greater methodological difficulties, it can be elicited by unconscious stimuli, although this was mostly found at the parietal site (e.g., Perrin et al., 1999; Bernat et al., 2001). P300a in the

present study was activated in the supraliminal condition, and although Lidell et al. (2004) found this ERP to be activated in the subliminal condition by considering it to represent the orientation stage, other backward masking studies found emotion modulation in the supraliminal condition at this latency range (e.g., Eimer & Kiss, 2008). Jeste and Nelson (2009), reviewing ERP components in autism, suggested that differences found in P300 in subjects with autism show that these differences are not a result of primary differences in low level processing, but probably represent dysfunctional neural circuits for higher level visual processing, including selective visual attention.

In the present study, it was expected that there would be group differences in processing of subliminal fearful faces, in accordance with evidence of the amygdala theory of autism (hypoactivation or hyper-activation of amygdala in autism), but the results of the present study show group differences in emotion processing mostly related to enhanced N200 for subliminal happy faces in the Low AQ group, but not in the Mid and High AQ groups. Several explanations can be given for these findings. Findings of impaired amygdala function in autism are conflicting, with some studies showing hypoactivation (e.g., Schultz, 2005), hyperactivation, or preserved amygdala function in autism (South et al., 2011), including during the presentation of subliminal anxious faces (Hall et al., 2010). These results suggest that the amygdala function in autism may not be absent, but its function depends on various factors, including the fixation to eye regions, gaze avoidance, and as the relevance detector network account suggests, abnormal fronto-amygdala connectivity, which reduces the modulatory role of the ventromedial prefrontal cortex (vMPFC) on the amygdala (Zalla & Sperduit, 2013). The socio-emotional deficit hypothesis of autism explains difficulties in emotion processing in this group by abnormal social attention and difficulties in preconscious emotion processing, including difficulties in evaluating the significance of socially salient stimuli (Dawson et al., 2002; Fein et al., 1986; Waterhouse et al., 1996; Kamio, Wolf, & Fein, 2006). Less efficient processing of salient stimuli in autistic subjects is related to prefrontal cortex dysfunctions (Zalla & Sperduit, 2013; Schmitz et al., 2006). Although research on the amygdala has focused primarily on its role in the processing of fear and threatening stimuli, there is increasing evidence of its role in the processing of positive emotions, particularly in stimulus-reward learning (Baxter & Murray, 2002).

The amygdala is highly interconnected with other structures, and Hall et al. (2010), examining subliminal processing of anxious faces, did not find dysfunctional amygdala in autism, but rather fusiform gyrus, suggesting that signalling salient information downstream

may be impoverished. An updated view of the amygdala theory of autism proposes that the brain circuit, in which the amygdala occupies a crucial place, is responsible for the detection of a larger category of biologically relevant stimuli, acting as a relevance detector and giving priority to salient signals, based on the motivation and contextual goals of the perceiver (Sander, Grafman, & Zalla, 2003; Zalla & Sperduit, 2013). Based on this proposal, socio-emotional difficulties in autism may be described as a disruption in a "Relevance Detector Network". According to the social relevance detector account of the amygdala, although the amygdala is able to process social information under the unaware condition, its important role is bringing to conscious awareness self-relevant information through emotional arousal (Vuilleumier & Schwartz, 2001). The importance of the limbic system in bringing experience to a conscious level has already gained support in some studies (Gloor et al., 1982), and self-related information processing is found to be associated with functional abnormalities in the vMPFC (Kennedy & Courchesne, 2008; Lombardo et al., 2009). The importance of both the amygdaloidal complex and prefrontal areas as a relevance detector (Sander et al., 2003) is also supported in cross-species comparative studies, which have pointed out the co-evolution of these structures in the neocortex (Barton & Aggleton, 2000), and that inputs from the amygdala reach almost 90% of the prefrontal cortex (Ememry et al., 1997). According to the relevance detection theory of autism, there is reduced top-down control and attentional modulation performed by the vMPFC in this group, leading to the inability of this prefrontal area to form salience maps for giving priority to specific environmental stimuli. As happy faces have been found to activate reward circuitry in neurotypical individuals (O'Doherty et al., 2003; Phillips et al., 1998), those findings may indicate decreased sensitivity to reward value of social stimuli not only in people with autism compared to typically developing controls, but also in individuals with higher autistic traits compared to individuals with lower autistic traits.

Happy faces, together with fearful faces, represent highly arousing stimuli (Juruena et al., 2010). A study showed that both happy and angry faces, when subliminally backward-masked, spontaneously produced distinct facial electromyographic (EMG) reactions in emotion-relevant facial muscles, showing that happy (and angry) expressions can be processed rapidly and automatically (Dimberg, Thunberg, & Elmehed, 2000). Williams et al. (2004) found amygdala activation for both fearful and happy faces under conditions of binocular suppression, although those two emotions showed distinct peaks of activity. Another study found increased amygdala activity in response to both fearful and happy facial

expressions when presented in the blind field of patients with unilateral occipital damage (Morris et al., 2001). These results support the hypothesis that the amygdala consists of distinct affective nodes that are differently activated by different emotions (Williams et al., 2004). Some studies proposed that positive stimuli are processed differently in the amygdala than negative stimuli (Dannlowski et al., 2007). As the amygdala has been reported to be both activated (Killgore & Yurgelum-Todd, 2004; Fitzgerald et al., 2006) and deactivated (Sheline et al., 2001, 2006) in response to happy faces, it is suggested that its activation to positive emotions may be a less consistent phenomenon than activation in response to negative faces (Dannlowski et al., 2007).

Specificity in responding to happy facial stimuli has been observed in people with autism. A recent study (Sepeta et al., 2012) found differences between typical and autistic children and adolescents in pupillary responses to happy facial expressions, with absent responses in autistic participants. Sims et al. (2012) found that participants with low AQ compared to participants with high AQ showed greater mimicry of happy faces conditioned with high reward compared to happy faces conditioned with low reward. Another study that examined the visual mismatch negativity (vMMN) in response to happy and sad deviant facial expressions in individuals with high and low AQ scores found smaller amplitudes of the vMMN to happy, but not sad, deviant faces in individuals with high AQ, showing less sensitivity to happy facial expressions in people with high autistic tendencies (Gayle, Gal, & Kieffaber, 2012). This study also showed a positive correlation between the AQ score and vMMN amplitude in response to happy faces, and no correlation was found with sad faces. These results were explained by the negative experience of social interaction by people with autism. Another study that examined dynamic facial expressions processing in people with higher and lower AQ showed greater low beta event-related desynchronisation (ERD) in response to angry than happy facial expressions, whereas people with high AQ showed greater low beta ERD in response to angry and neutral faces. In addition, the low AQ groups also had greater low beta ERD to happy faces compared to the high AQ groups. As the ERD of the alpha and low beta bands over sensorimotor areas representing mu-rhythm suppression is considered to be an index of the human mirror neuron system (hMNS), the results of this study are interpreted as showing greater hMNS activation to negative facial expressions in individuals with high autistic traits, and greater hMNS activation to positive stimuli in individuals with low autistic traits.

In conclusion, the present study shows that individuals with low and high AQ differ in subliminal face processing and particularly in processing of subliminal happy faces, suggesting that their differences may be based on the saliency of stimuli. However, further examination is necessary with a larger number of participants and some methodological improvements. Studies that examine subliminal and supraliminal facial emotion processing differ in methodological approaches, which make a final conclusion difficult to obtain. For example, individual differences in visual awareness should be taken into consideration and better control of subjective awareness in general. As in the present study where an explicit emotion recognition task was used, it can be questioned if similar results would be obtained for a task that does not require explicit emotion recognition. Another important factor that may have influenced the present results is the mask itself. Many studies employing a backward masking technique have used neutral faces, with a goal to mask the presence of the fearful faces. However, in studies that use both neutral faces and other facial expressions besides fearful faces, this may be problematic. For example, Kim et al. (2011) found greater amygdala activation to face-masked fearful faces compared to happy faces, and decreased amygdala activation to fearful compared to happy faces when the pattern mask was used. However, overall results of the present study show that individual differences in autistic traits in the general population need further investigation concerning the differences in emotion processing between individuals with higher and lower autistic traits.

CHAPTER 8 –

EXPERIMENT 3:

Biological Motion Processing in the Broad Autism Phenotype: A Magnetoencephalography Study

8.1. Introduction

An important human social ability is inferring other's intentions from non-verbal behaviour such as from body postures and gestures (Hari & Kujala, 2009). Biological motion (BM) refers to the representation of human and animal actions using point-light displays (PLDs), and is considered to represent an important tool for recognising non-verbal behaviour. Point–light displays are generated by attaching point-lights to key joints of a moving actor and filming the results (Johannsson, 1973; see Blake & Shiffrar, 2007, for a review). The sparse visual information provided in these types of displays requires global integration of motion signals (Ahlström et al., 1997). It is possibly to extract various types of information from point-light motion, including the identity of the moving stimulus (Cutting & Kozlowski, 1977), gender (Kozlowski & Cutting, 1977) or emotion (Dittrich, 1993).

It has been hypothesised that the brain has specialised networks for the processing of biological motion. These networks are thought to include the superior temporal sulcus (STS) and surrounding regions (Jokisch, Daum, Suchan, & Troje, 2005; Kim, Doop, Blake, & Park, 2005). The superior temporal cortex is a central component of the neural circuitry that mediates our ability to utilise the "Theory of Mind" (ToM) (Baron-Cohen et al., 2000), describing an ability to represent mental states of others. Biological motion also activates the network called the "mirror neuron" system (MNS) or the action observation/execution matching network which is activated both when an action is observed and performed (Rizzolatti & Craighero, 2004). The main idea behind using biological motion stimuli for examining the MNS is based on hypothesis that observing actions of other's may lead to unconscious "mirroring" of those actions (Rizzolatti & Craighero, 2004; Rizzolatti & Sinigaglia, 2010).

The MNS network consists of the premotor cortices, the inferior frontal gyrus (IFG), and parietal regions. In their fMRI study, Saygin et al. (2004) were first to find a clear response to point-light biological motion animations in frontal areas (the premotor brain regions containing mirror neurons) known to be activated by action observation. This study showed that perception of motion cues of body actions activated inferior frontal and premotor areas known to be involved in action observation responded solely to motion cues of actions. Their results also showed a very similar pattern of the BOLD response in frontal areas to those in posterior superior temporal sulcus (pSTS), an area whose importance in biological motion processing in already established.

Event related desynchronization (ERD) of the alpha range component of mu rhythm (8-13 Hz oscillation), or mu suppression, over sensorimotor cortex is considered to be an index of the MNS and occurs during viewing, performing and even imagining movement. Mu suppression is particularly pronounced when the viewed movement or action is socially relevant (Ulloa, & Pineda, 2007). For example, previous studies found mu rhythm suppression to biological motion but not to scrambled motion (Ulloa & Pineda, 2007) and to biological motion stimuli containing various emotions with an explicit task of distinguishing the intention, emotion and gender of the stimuli (Perry et al., 2010).

It is suggested that autism spectrum disorder (ASD) is a strongly genetically determined developmental disorder characterised by diverse problems, including social impairments, communication impairments, and restricted and stereotyped patterns of behaviour, interests, and activities (American Psychological Association, 1994). Impairments of socio-cognitive functions in ASD led to the "broken mirror" hypothesis as one of the important neural substrates of the disorder, often mentioned as dysfunctional parieto-frontal mirror system (e.g., Perkins, Stokes, McGilivray, & Bittar, 2010). Previous neuropsychological studies on (impaired) BM detection in children and adults with autism are inconclusive. Whereas typically developing subjects show significant mu suppression during observation of biological motion, this suppression is reduced or absent in individuals with autism (e.g., Oberman et al., 2005). Some studies, although not finding any difference in recognition of BM between autistic and healthy subjects on the visual processing of simple actions, found that autistic subjects have problems in the interpretation of the internal states of others (Moore et al., 1997), that is, impaired recognition of emotional point-light displays (Hubert et al., 2007; Parron et al., 2008). Recent fMRI studies that compared the processing of biological and scrambled motions in autistic and control subjects support differences in processing of BM in people with ASD and typical controls (Freitag et al., 2008; Herrington et al., 2007). This study showed that the most significant difference between ASD and control group is that the ASD group showed less activation in the right Superior Temporal Sulcus (STS), which is known to be a central structure in BM processing (Freitag et al., 2008).

An indirect method to gain information about social processing on the autism spectrum, and particularly on the genetics of autism, is to examine patterns of autism in first-degree relatives and mild autistic traits. The expression of milder and non-clinical autistic characteristics among relatives of individuals with autism is referred to as the broader autism phenotype (BAP) (Scheeren & Stauder, 2008). Autism is marked by social difficulties and

some of these difficulties have also been reported in first degree relatives of individuals with autism. For example, atypicalities were found among parents of individuals with autism in face processing (Wallace et al., 2011), facial expressions of emotions (Spencer et al., 2011), facial identity (Wilson et al., 2010), and gaze patterns during viewing of faces and facial emotions (Adolphs, 2008; Scheeren & Stauder, 2008).

The aim of this study was to examine biological motion processing over selected brain regions (by using MEG), and to examine if there are significant differences in a group of parents and adult siblings of individuals with autism (in further text will be referred as "ASD relatives" or "relatives") and control subjects with no family cases of autism. Additionally, the design aimed to look at differences in biological motion processing between typical subjects with no relatives with autism, divided into groups of low and high autistic tendencies as measured by the Autism Spectrum Quotient (AQ) questionnaire. The main aim was to compare individuals with high and low autistic traits on biological motion tasks, and also to compare them to the first-degree relatives of individuals with autism to see if they differ or show similarity to any of those groups that are opposite on the autism spectrum quotient. Based on previous findings of atypicalities usually present in ASD and that are found in milder form in ASD relatives, it is proposed that the relatives group will show more similarities with subjects with higher autistic traits, and less similarities with subjects with lower autistic traits.

Time-frequency analysis will be computed within three bands: alpha (8-13 Hz), beta (14-30 Hz) and gamma (30-60 Hz). Stimuli that represent biological motion (with recognising Direction and Emotion from stimuli), compared to Scrambled motion and the Circle as a baseline stimuli will be shown. The main aim is to distinguish brain activation during biological motion compared to non-biological motion (in further text those non-biological motion conditions will be named "Scrambled condition" and "Circle condition"), and to look at differences between two biological motion conditions that require recognition of emotions and recognition of Direction (in further text: "Emotion condition" and "Direction condition"). It is proposed that larger group differences, particularly differences between autistic relatives and individuals with the low AQ, and also between high and low AQ groups, would be seen in relation to Emotion condition compared to non-biological motion conditions, as well Direction condition. This is based on suggestions that relate the MNS to theory of mind (ToM) abilities, which refers to the ability to represent the mental states of others. It is proposed that the function of mirror neurons might be part of, or a precursor of, a

human ability to assign and understand goals, intentions and beliefs of other people (Gallese & Goldman, 1998; Rizzolatti et al., 2001). The link between the MNS and mind reading ability is of particular interest to autism research as individuals with autism often show impaired recognition of other peoples' intentions, or state of mind (impaired ToM) (Baron-Cohen, Leslie, & Frith, 1985), and it is suggested that early disruption in the MNS could be a cause of various impairments found in autism, including difficulties in imitation, ToM and communication (Dapretto et al., 2005).

As two major frequency bands at about 10 and 20 Hz have been observed over the Rolandic (mu rhythm) area (Hari & Salmelin, 1997) they are of particular relevance for this study. Previous electroencephalographic and MEG studies have recognised the origin of the 20-Hz oscillations in the anterior bank of the central sulcus and 10-Hz oscillations in the post-central cortex (Salmelin & Hari, 1994; Salmelin, Hämäläinen, Kajola, & Hari, 1995). Beta rhythms oscillation (within 15-30 Hz range) over the primary motor cortex (M1) has been found to be a sign of motor cortical activity (Tamura et al., 2005), with several MEG studies showing modulation of Beta oscillations during both action execution (e.g., Kilner et al., 2000, 2003a, b) and action observation (e.g., Kilner, Marchant, & Frith, 2009; Press, Cook, Blakemore, & Kilner, 2011). The M1 cortex has relevance for social information processing as it is considered to be downstream from a core area of the MNS - the inferior frontal gyrus (IFG) (Caetano, Jousmäki, & Hari, 2007; Hari et al, 1998). On the other side, suppression of alpha rhythm over parietal regions was particularly evident by social relevance of the experimental task (Kilner, Marchant, & Frith, 2009).

One particularly important region where we expect group differences and differences between conditions to emerge is the Superior Temporal Sulcus (STS). The STS plays a crucial role in the neural circuitry that mediates our ability to utilise the ToM (Baron-Cohen et al., 2000). The STS also has an important role in the MNS (Rizzolatti & Craighero, 2004). Another region that we predict will show significant differences between relatives and high AQ participants when compared with low AQ participants is the pars opercularis of the inferior frontal gyrus (Brodmann's area 44). Pars opercularis is considered to be the frontal component of the MNS and is thought to represent the human homolog of the ventral premotor cortex (area F5) of the macaque, an area where mirror neurons were first observed during action observation and execution in monkeys (Iacoboni et al., 1999; Rizzolatti & Craighero, 2004). Activity in this area is found to be absent in children with autism when compared to typically developing children during imitation and viewing of facial emotional

expressions, and was also found to be negatively correlated with social symptoms in children with autism (Dapretto et al., 2005).

Based on previous findings, the main hypothesis of this study is that alpha rhythm over primary somatosensory cortex (S1) and gamma band activation over STS would show stronger modulation for more socially relevant stimuli, that is, biological motion stimuli, and particularly for the Emotion condition. Sensorimotor Beta oscillations are expected to show strong modulation during viewing of biological motion stimuli, consistent with the role of STS in MNS, and it is also expected to show strong activation under socially relevant Emotion conditions. It is expected that individuals with higher autistic traits and the ASD relatives group would show weaker Beta oscillations for biological motion stimuli when compared to non-biological motion stimuli (Scrambled and Circle condition), and particularly the Emotion condition.

8.2. METHODS

8.2.1. Participants

Forty-two paid volunteers took part in the MEG study (**Table 8-1**). Participants completed online questionnaires: the Autism Spectrum Quotient (AQ), the Empathy Quotient (EQ) and the Systemizing Quotient (SQ). Participants with non-autistic relatives were selected based on their AQ scores, after completing the online Autism Spectrum Quotient (AQ) and only those belonging into low (AQ < 11) and high (AQ > 21) AQ groups were selected. First degree relatives also completed the online AQ questionnaire, but they were invited for MEG testing regardless of their AQ scores. During data analysis, 8 participants were removed because of extensive artefacts, and the final number of participants consisted of 13 participants belonging to the high AQ group, 11 in the low AQ group and 10 in the ASD relatives group. All participants completed the Raven's matrices test before or after the MEG scan. All participants had normal or corrected-to-normal vision, with no neurological impairment. All participants signed informed consent to participate and the experimental procedures were approved by the ethics committee of the Swinburne University of Technology, Melbourne, Australia.

Table 8-1: *Participants' characteristics*

Participants

Groups		AQ score	EQ score	SQ score	Raven's	Age	Years of Education
Low AQ (n = 13, 6 F; 2 left-handed)	Mean	10.92	47.85	46.23	20.31	28.92	16.22
	Std. Error of Mean	2.049	3.270	3.523	1.766	1.631	1.321
	Std. Deviation	7.388	11.789	12.703	6.369	5.880	3.962
	Minimum	4	23	28	7	20	12
	Maximum	26	67	71	32	41	24
High AQ (n = 12; 6 F; 2 left-handed)	Mean	25.83	30.92	74.17	21.58	25.50	15.42
	Std. Error of Mean	1.308	3.870	6.812	1.515	2.098	.723
	Std. Deviation	4.529	13.406	23.598	5.248	7.268	2.503
	Minimum	21	10	23	8	18	13
	Maximum	33	59	112	27	38	21
ASD Relatives (n = 10; 2 F; 3 left-handed)	Mean	17.80	45.50	61.80	20.00	36.20	13.50
	Std. Error of Mean	1.672	3.698	6.018	1.498	4.543	1.708
	Std. Deviation	5.287	11.693	19.031	4.738	14.367	5.401
	Minimum	9	29	26	10	20	0
	Maximum	25	67	90	24	54	18

8.2.2 Measures

All participants completed online questionnaires: the Autism Spectrum Quotient (AQ), the Empathy Quotient (EQ), and the Systemizing Quotient (SQ) questionnaires. Participants also completed the Advanced Raven's Progressive Matrices before or after EEG testing.

The Autism Spectrum Quotient (AQ) consists of 50 questions measuring the degree to which a person with normal intelligence has autistic traits (Baron-Cohen et al., 2001; Woodbury-Smith et al., 2005). Participants respond using a 4-point rating scale, from "definitely agree" to "definitely disagree".

The Empathy Quotient (EQ) questionnaire consists of 40 questions qualitatively assessing empathy level (Baron-Cohen & Wheelwright, 2004). Individuals with autism have shown lower scores on the EQ when compared to neurotypical controls (Baron-Cohen & Wheelwright, 2004). Recently, lower scores on the EQ were found in fathers of children with autism (Sucksmith et al., 2013).

The Systemizing Quotient (SQ) consists of 80 items and measures individual differences in a drive to "systemise" (Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003). Systemising refers to the drive to analyse and construct rule-based systems.

The Raven's Advanced Progressive Matrices test is a standardised intelligence test measuring mostly the nonverbal domain. It consists of visually presented geometric figures where one part is missing and a correct missing part must be selected from offered answers to complete the design (Raven, 2000; Kunda, McGreggor, & Goel, 2009). It has been used with individuals with autism, although results seem different compared with Wechsler's test, (Dawson et al., 2007; Soulières et al, 2011a). In the current study, we used the Raven's test with a time limit of 30 minutes.

8.2.3. Stimuli

Stimuli were point-light displays (PLDs) composed of 15 white dots presented against black background showing the human actions of walking representing biological motion sequences (intact PLD walkers), scrambled motion sequences devoid of meaningful configural information and moving circle sequences (**Figure 8-1**). Biological motion PLDs consisted of fearful and happy emotional walking actions. Scrambled PLDs matched each of biological motion PLDs. All stimuli, including Circle and Scrambled stimuli, consisted of the same dots and were moving towards the right and towards the left. Stimuli of 3 seconds duration were chosen because preliminary research with stimuli showed that participants showed best recognition of Emotion for that duration. Stimuli were created at the Martin Giese lab, Section for Computational Sensomotorics, Tüebingen University.

Figure 8-1. Examples of stimuli

Biological motion   Scrambled motion   Circle
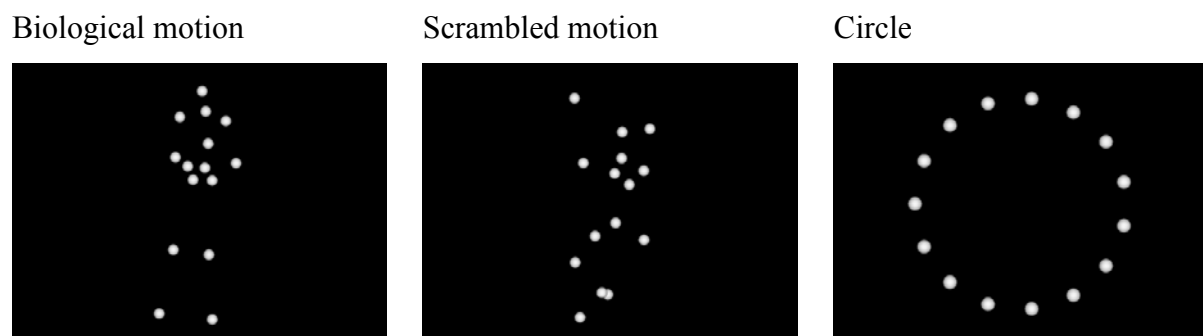
8.2.4. Procedure

Subjects sat in a magnetically shielded room (MSR) at the distance of 1.15m from the screen and watched a series of video clips each lasting 3 s. Each block started with a written instruction describing the task, followed by the black screen for 500 ms, then a fixation cross at the centre of the screen displayed for 750 ms, another black screen for 500 ms, after which stimuli were presented for the duration of 3 s. In each video clip, the subject saw point-light figures depicting various movements. The experiment consisted of separate presentation of four conditions: Scrambled, Direction, Emotion and Circle conditions. Emotion and Direction represented two "biological motion" conditions and the same stimuli (fearful and happy biological motion displays) were used for both biological motion conditions. Each condition was presented in separate blocks. The experiment started with the "Scrambled" condition, while the "Emotion" and "Direction" conditions were presented in random order, and the "Circle" condition was always the final stimulus. This order was chosen so that the Scrambled condition can be seen before biological conditions and that knowledge of biological conditions does not influence data. It is also possibly that the present order of stimuli can influence data in unexpected ways. Participants saw an instruction before each condition directing them towards the task in each block. Each task consisted of counting rare events, and participants were informed in advance that there would always be between 3 and 6 events. The main reason for informing participants about the possible number of events was to reduce the mental task of remembering, so that they could focus on recognising the task conditions. At the end of each block, they were asked to show with their fingers the number of rare events. In the Scrambled condition, Scrambled point-light walkers were displayed along with several "rare" biological motion displays. Participants were required to remember how many biological motion displays they saw and report them at the end of the block. In the Emotion condition, one block consisted of dominant fearful point-light displays and 3-6 happy displays, and another block consisted of dominant happy displays and rare fearful displays. In the Direction condition, some fearful and happy point lights were shown like in the Emotion condition, but participants were asked to recognise the Direction of the moving stimuli. In one block, stimuli were moving predominantly towards the right, and participants were asked to recognise and report at the end of the block number of stimuli moving to the left, and vice-versa for another block. In the Circle condition, the participants were asked to recognise the direction of rotation of the moving Circle, and to remember and report at the

end of the block the number of stimuli moving in the rare Direction. All conditions consisted of 96 trials, except the Circle condition that consisted of half that number.

8.2.5. Data acquisition (MEG Recording)

Magnetic fields were recorded with a whole head 306-channel MEG system comprised of 204 planar gradiometers and 102 magnetometers in a supine/upright position (Elekta Neuromag® TRIUX, Helsinki, Finland). The individual head shape of each participant with localisation coils was registered with a Polhemus FASTRAK head digitising system. The head position of the subjects was measured at the beginning of data acquisition using the continuous head position indicator (cHPI). Before the measurement, small coils (known as Head Position Indicator coils (HPI)) were attached to the head (two placed on the auricles, three on the forehead) and their location was digitizes on the head. These coils are then used during the measurement to measure the location of the head. After that continuous head position tracking is enabled (cHPI) allowing correction for potential movements of the subject's head. The neuromagnetic activity was continuously recorded employing a sampling rate of 1000 Hz and a bandwidth from 0.1 to 330 Hz.

8.2.6. Data processing and analysis

All raw MEG data were pre-processed with the temporal signal-space separation method (tSSS) (Taulu & Simola, 2006; Taulu & Hari, 2009) using MaxFilterTM software (version 2.2, Elekta Neuromag Oy, Helsinki, Finland). The procedure eliminates environmental and movement noise and in this way enhances the signal-to-noise ratio of the data (Taulu, Kajola & Simola, 2004). The remaining analyses were performed with Brainstorm software (http://neuroimage.usc.edu/brainstorm/) (Tadel, Baillet, Mosher, Pantazis, & Leahy, 2011). The data were grouped in 4 conditions (Scrambled, Direction, Emotion and Circle) and then processed separately for each condition. Raw data were epoched between -1200 ms pre-stimulus and 3000 ms post-stimulus onsets, and the baseline period was defined as -1200 ms to -500 ms before the stimulus onset. In this way, the baseline period included only the time window for which the white cross was displayed on the black screen. Additionally, the data were band-pass filtered between 1-65 Hz. Then MEG data were visually inspected, and trials with significant eye movements or blinks (excessive artefacts) were removed from the analysis. Detection of eye blinks and cardiac events was performed automatically using default parameters implemented in Brainstorm software, with

additional visual inspection. Only data with more than 50% of artefact-free trials were used for further analysis.

8.2.7. Source space analysis

Time-frequency decomposition was performed in selected regions: primary motor cortex (M1), primary sensory cortex (S1), STS and pars opercularis. Those regions were selected based on the previous research on biological motion and MNS activity. The overlapping spheres approach was used for obtaining an individual head model and the standardised MNI/Colin27 brain template of the Montreal Neurological Institute (MNI, http://www.bic.mni.mcgill.ca) was employed. Furthermore, the Minimum Norm Estimation (MNE) was used to estimate the distributed source model of the MEG signals, recorded from the entire head surface, in order to get the current strength dynamics of cortical sources (Hämäläinen & Ilmoniemi, 1994).

Time-frequency decomposition based on complex Morlet wavelet transformation was performed in the source space to determine changes in power within the following frequency bands: alpha (8-13 Hz), beta (14-30 Hz) and gamma band (30-60 Hz). A complex Morlet's wavelet with a Gaussian reference shape (temporal resolution 3 seconds, central frequency 1 Hz) was used, producing a spectrogram of the MEG signal power at each frequency within an epoch (Tallon-Baudry & Bertrand, 1999). The wavelet decomposition was performed for each trial (providing induced MEG responses), and data were subsequently averaged across each condition. Averaged data were z-score normalised. Z-score normalization produces a z-score map, resulting from the statistical comparison between stimulation and baseline as computed for each time–frequency band. A baseline from -1200 ms to -500 ms pre-stimulus was used. Although the pre-stimulus period was longer, the first and last 500 ms, consisting of a blank screen, were not used in order to avoid contamination of artefacts that can appear close to starting and completing a trial. A Wilcoxon signed ranked test (non-parametric test) was used to determine the significance of change in beta power in each group and for each condition.

8.2.8. Sensor space analysis

Time-frequency decomposition was performed for each trial, for each sensor and for each subject. For each group and condition 2-D sensor space maps were calculated over baseline-corrected data in order to obtain the topography of activation for each frequency

band. Also, time frequency maps over 8-60 Hz were computed over all sensors to examine overall activity.

8.2.9. Statistical analysis

Statistical analysis of the normalised suppression was performed by a repeated-measures ANOVA using within-subject factor for the condition (Scrambled, Direction, Emotion) and Hemisphere (left vs. right), and between-subject factor comparing three groups separately: Low and High AQ groups and ASD Relatives group. Greenhouse-Geisser corrections were applied when suitable, with Fisher's Least Significant Differences (LSD) test used for post-hoc comparisons. The AQ groups were also collapsed to create a Non-Relatives group as required. A paired comparison t-test also applied to examine differences between conditions, and also hemispheric lateralisation. Planned comparisons also included collapsing AQ groups into the Non-Relatives group to see if difference can be seen more at the level of the Non-Relatives group vs the Relatives group, or between Low and High AQ groups. Statistical analyses were restricted from 0 to 2700 ms (2.7 s) to ensure that no edge effects for power bands influenced results.

Comparisons were first performed for the three main conditions: Scrambled (as non-biological motion condition), Direction, and Emotion conditions (biological motion conditions). The Circle condition was used as a baseline condition, suggesting that larger differences between baseline and other conditions mean higher activity. However, this condition consists of a smaller number of trials than other conditions, and therefore was not included in repeated measures ANOVA.

Spearman's non-parametric correlations were applied to examine correlations between alpha and beta band decreases for conditions and various measures in each group.

8.3. RESULTS

8.3.1. Behavioural

One-way ANOVA was applied to examine group differences for various measures. Concerning AQ scores, there were significant differences between all groups ($p < 0.03$ for all groups). Participants in the Low and High AQ groups were preselected based on their AQ scores, representing higher and lower scores on the AQ questionnaire. However, it is interesting to observe that AQ scores found in the ASD Relatives group put this group in the

middle of the measure. Obviously, a larger sample would allow more detailed exploration regarding the level of autistic tendency in non-affected siblings and parents of individuals with autism.

Significant group differences were found for the EQ scores, with lower scores in the High AQ group when compared to both the Low AQ (p = 0.01) and the Relatives group (p = 0.04). These results show that the empathy scores in the Relatives group are closely related to the Low and not the High AQ group. On the other side, significantly larger SQ scores were found for the High AQ group when compared to the Low AQ group (p = 0.003), and although the Relatives group scores did not significantly differ from any of groups when using the Bonferroni adjustment, marginally significant differences (p = 0.06) were found when using the LSD (Least Significant Difference) test), indicating slightly larger scores for the Relatives group compared to the Low AQ group (p = 0.06). This indicates that SQ scores in the Relatives group are closer to the High AQ group, although mostly occupying a middle place between those groups. However, high SQ scores in the Relatives group should not be automatically related to first-degree relatives of individuals with autism. It has been shown that males have higher levels of systemising than females (Nettle, 2007), and the Relatives group in this study consists of predominantly male participants. AQ, EQ and SQ scores are graphically shown in **Figure 8-2**.

No group differences were found for Raven's scores, indicating that the level of non-verbal intelligence was equally distributed among groups. No statistically significant group differences were found for Age, although the Relatives group generally consisted of older participants. However, after removing one female participant in this group due to extensive artefacts, the Relatives group consisted of predominantly male participants (with only two females). Younger participants in this group were mostly adult siblings of individuals with autism, whereas the older participants were mostly parents, and number of siblings and parents was equal (altogether, 5 siblings and 5 parents).

Figure 8-2. AQ, EQ and SQ scores across groups

Error Bars: +/- 1 SE
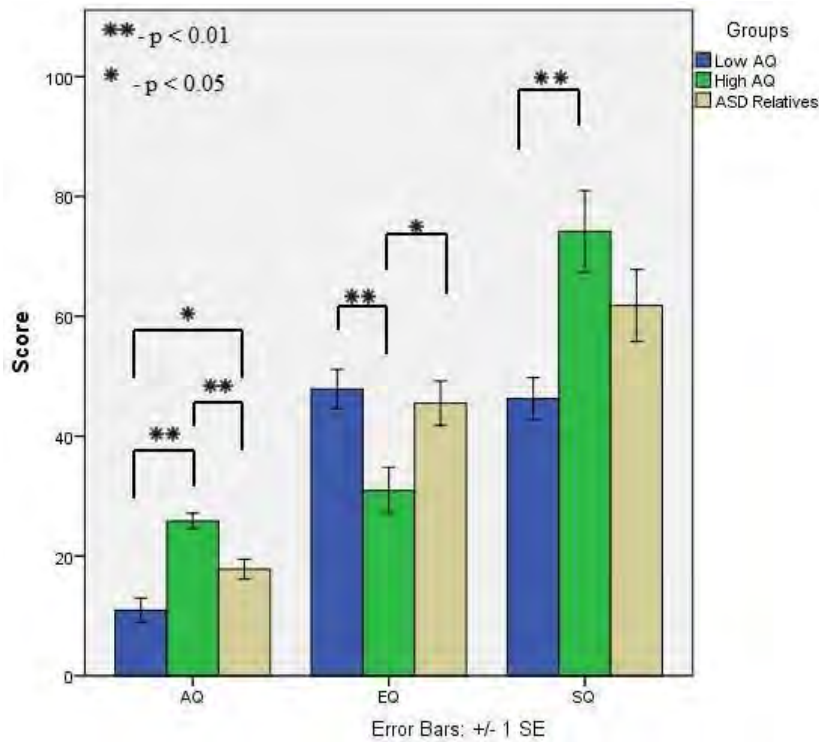
8.3.2. Correlations

Non-parametric one-tailed Spearman's correlation was applied between measures (**Figure 8-3; 8-4; 8-5; 8-6**). Results revealed a negative correlation between AQ and EQ scores ($r = -0.69$, $p = 0.001$) and a positive correlation between AQ and SQ scores ($r = 0.69$, $p = 0.001$). A negative correlation was also found between EQ and SQ scores ($r = -0.4$, $p = 0.01$). In addition, a positive correlation was also found between EQ scores and Age ($r = 0.42$, $p = 0.01$), indicating higher EQ scores in older participants.

Figure 8-3. Correlation: AQ x EQ
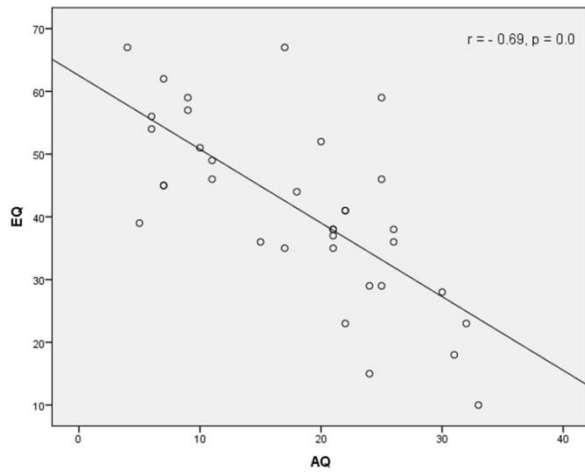
Figure 8-4. Correlation: AQ x SQ
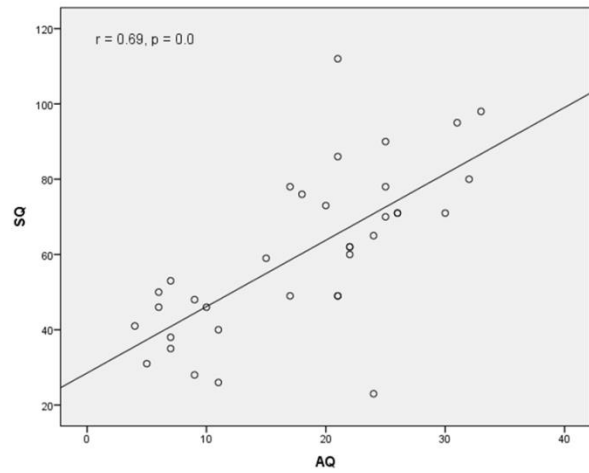
Figure 8-5. Correlation: EQ x SQ
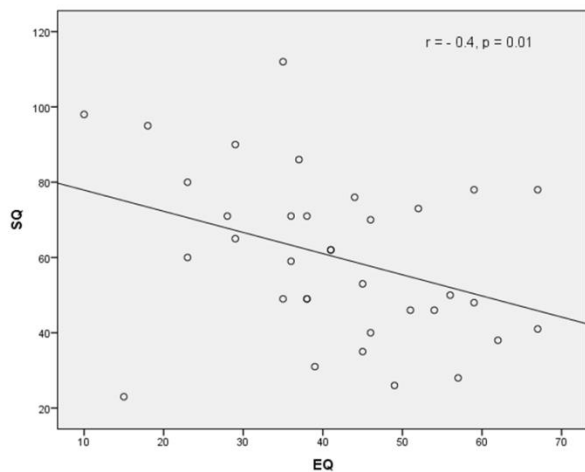
Figure 8-6. Correlation: EQ x Age
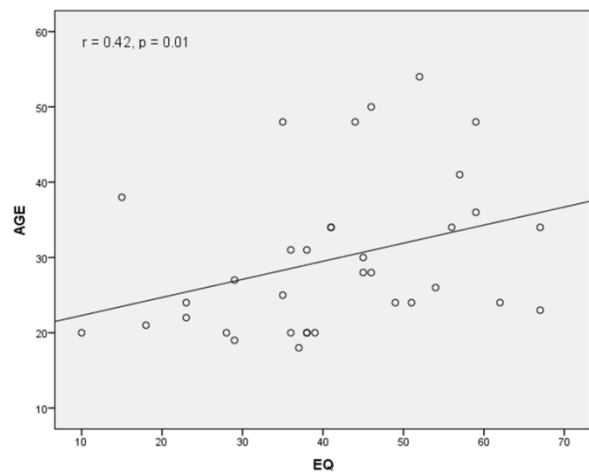
Correlations were examined for each group (**Figure 8-7, 8-8, 8-9, 8-10**). For the Low AQ group, AQ scores correlated negatively with EQ scores ($r = -0.56$, $p = 0.03$) and positively with SQ scores ($r = 0.51$, $p = 0.04$). For the High AQ group, AQ score correlated negatively with EQ scores ($r = -0.56$, $p = 0.03$). For the Relatives group, AQ scores correlated positively with SQ scores ($r = 0.61$, $p = 0.03$).

Figure 8-7. Correlation: AQ x EQ (Low AQ)   **Figure 8-8.** Correlation: AQ x SQ (Low AQ)
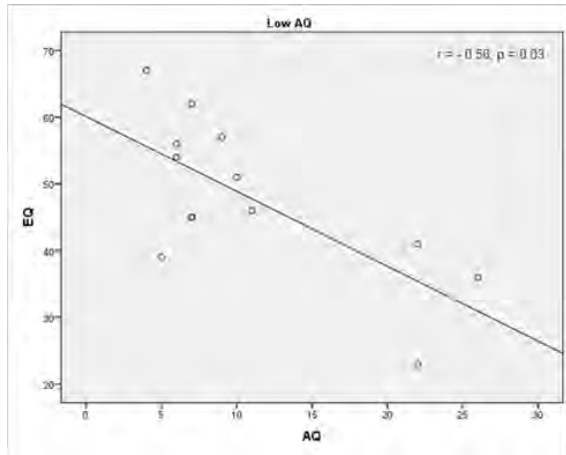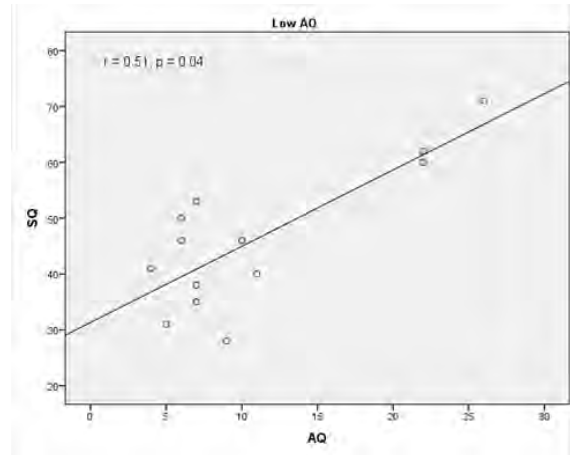
Figure 8-9. Correlation AQ x EQ (High AQ)   **Figure 8-10.** Correlation: AQ x SQ (ASD Relatives)
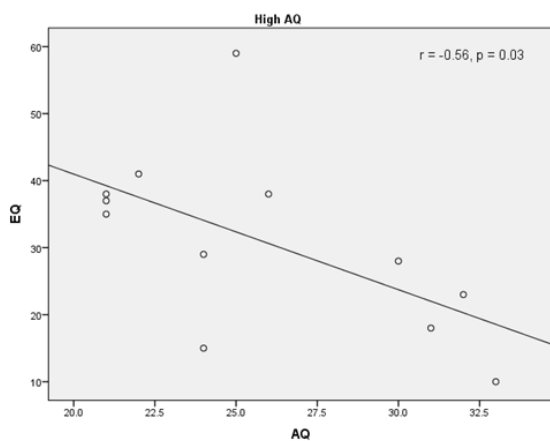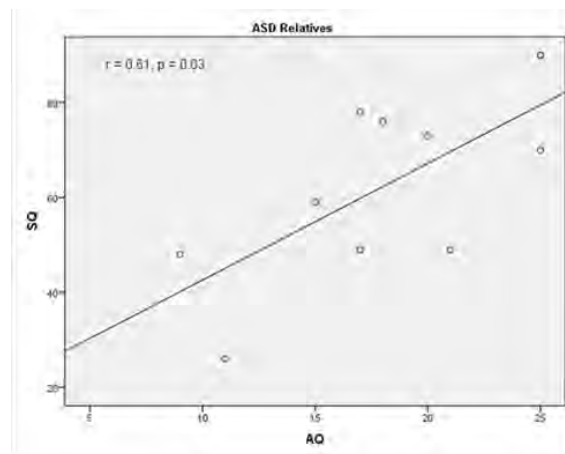
8.3.3. Condition effect across all groups

Across all subjects and both hemispheres, a significant effect of condition was found for beta decreases over M1 ($F_{(2,62)} = 4.01$, $p = 0.02$), indicating larger beta decreases for Scrambled than Direction condition ($p = 0.03$), and also over STS ($F_{(2,64)} = 4.35$, $p = 0.02$), indicating larger beta decreases for Emotion ($p = 0.01$) and Direction ($p = 0.05$) compared to Scrambled condition. Further analysis for each hemisphere revealed that over the M1, condition effect was significant mostly in the left hemisphere ($F_{(2,62)} = 6.28$, $p = 0.003$), whereas for the STS, condition effect was significant mostly in the right hemisphere ($F_{(2,64)}$

= 3.36, p = 0.04), with similar activation as explained previously for bilateral activation for both regions.

Although condition effect across all subjects was not found in other regions, significant condition x Group (all three groups) interaction was found for beta decreases over S1 (marginally found bilaterally, $F_{(4,62)} = 2.32$, $p = 0.07$). Over S1, ANOVA for each group revealed a significant effect of condition ($F_{(2,18)} = 3.52$, $p = 0.05$) only in the Relatives group, indicating smaller beta decreases for Direction compared to Scrambled and Emotion conditions (all comparisons, $p < 0.05$) (further analysis for each hemisphere revealed that this effect was significant only in the left hemisphere, $F_{(2,18)} = 5.33$, $p = 0.02$). Over pars opercularis, ANOVA also indicated significant effect of condition (in the left hemisphere, $F_{(2,18)} = 3.95$, $p = 0.04$) for the Relatives group only, with lager beta decrease for Scrambled and Emotion conditions compared to Direction condition (both comparisons, $p < 0.05$).

Across all conditions, a marginally significant effect of Group was found for beta decreases over the M1 ($F_{(1,31)} = 2.99$, $p = 0.07$) and the S1 ($F_{(1,31)} = 3.68$, $p = 0.04$), showing larger beta decreases for the Relatives group *cf* the High AQ group ($p = 0.04$). This effect over the M1 was mostly significant only in the left hemisphere ($F_{(1,31)} = 3.42$, $p = 0.05$), with larger beta decreases for the Relatives group *cf* the Low AQ group ($p = 0.05$).

No significant effect of condition was found for alpha decreases over the S1.

8.3.4. Hemisphere effect

Across all subjects and conditions, significant effect of hemisphere was found for beta decreases across all examined regions, and also for alpha decreases over the S1 (all regions, $F > 12.3$, $p < 0.03$), indicating larger power decreases in the right hemisphere. Further analysis with paired-samples t-test was used to see if the hemisphere effect could be seen in both biological motion and non-biological motion conditions. Results showed that larger beta decreases can be seen only for biological motion conditions (Direction and Emotion) (all regions, $p < 0.03$), but not for non-biological conditions (Scrambled and Circle), as shown for beta decreases over the M1, S1, STS and alpha decreases over S1. However, for beta decreases over the par opercularis region, larger decreases over the right hemisphere were found for Scrambled and Direction ($p = 0.04$). For beta decreases over M1, decreases were stronger for Emotion ($p = 0.001$) than Direction ($p = 0.05$) condition. Only beta activity over

M1 showed a tendency for some condition x hemisphere interaction, but without reaching statistical significance (p = 0.09).

Further ANOVA also found hemisphere x Group interaction for beta decreases over S1 (F(2,31) = 3.07, p = 0.06) (marginally significant), pars opercularis (F(2,32) = 3.87, p = 0.03) and STS (F(2,32) = 4.21, p = 0.02), and an additional t-test was performed to examine hemisphere lateralisation for all conditions in each group. Over S1, the High AQ group showed significant hemisphere effect in Direction condition (p = 0.01), and the Relatives group showed significant effect both in Direction and Emotion conditions (both conditions, p < 0.04). (When creating the Non-Relatives group, they showed right hemisphere lateralisation for Direction condition, p = 0.002). Over pars opercularis, only the Relatives group showed hemispheric lateralisation for the three main conditions (all main conditions, p < 0.04). Over STS, marginally larger decrease in the left hemisphere for Direction condition was found in the Low AQ group (p = 0.06), with no significant effect for the High AQ group. However, the Relatives group showed a significant effect for all main conditions (all main conditions, p < 0.04), but not for the Circle condition. Results over Opercularis and STS indicated that there was not significant hemisphere lateralisation for any condition in the Non-Relatives group.

Although no hemisphere x Group interaction was found for beta decreases over M1, at this region, significant right lateralisation for Emotion condition (p = 0.01) was found in the Low AQ group, and marginally for Direction condition (p = 0.06) in the High AQ group. When AQ groups were collapsed into the Non-Relatives group, a paired t-test revealed significant hemisphere lateralisation with larger beta decrease in the right hemisphere for both biological motion conditions, with no lateralisation for non-biological motion conditions. However, no hemispheric lateralisation was seen in any of the conditions for the Relatives group.

Alpha power decreases over S1 also did not show a significant Hemisphere X group interaction, but a t-test for each group showed this effect of hemispheric lateralisation for both biological motion conditions in the Low AQ (both conditions, p < 0.04) and the Relatives groups (both conditions, p < 0.05). However, the Relatives group also showed this effect for the Scrambled condition (p = 0.02). (When AQ groups were collapsed into the Non-Relatives group, the effect was seen only for Direction condition, p = 0.01). No hemispheric lateralisation was found in the High AQ group

8.3.5. One-way ANOVA

The one-way ANOVA was examined to clarify group differences. Bonferroni adjustment ($p < 0.05$ considering to be significant) for multiple comparisons was used in reported results.

The one-way ANOVA for each region revealed that the Relatives group showed a tendency to have larger beta decreases for Scrambled condition when compared to the Low AQ group, particularly in the right hemisphere for beta decreases over S1, STS and also alpha decreases over S1, but in the left hemisphere for beta decrease over M1 and pars opercularis. However, significantly larger decreases for the Scrambled condition in the Relatives group compared to the Low AQ group were found only for beta decrease over M1 (LH, $p = 0.01$). At this region, is interesting that suppression for the Scrambled condition in the left hemisphere was found to be largest for the Relatives group, followed by the High AQ group, and smallest in the Low AQ group, although only difference between the Low AQ and the Relatives groups reached statistical significance (although it was also marginally larger than for the High AQ group, with $p = 0.06$). **Figure 8-11.** shows Scrambled condition in the left hemisphere for each group.

The Relatives group also showed larger beta decreases over S1 for Emotion condition in the right hemisphere compared to both Low and High AQ groups (comparison with both groups, $p < 0.02$), and for beta decrease over pars opercularis when compared to the High AQ group ($p = 0.05$).
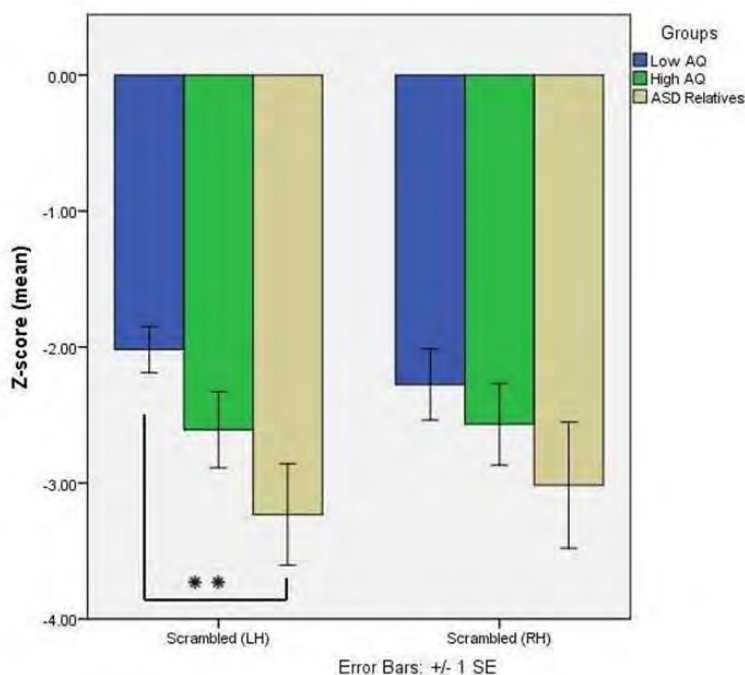
Figure 8-11: Scrambled condition.The one-way ANOVA showed statistically larger beta decreases over M1 for Scrambled condition in the Relatives group when compared to the Low AQ group. However, this group showed a tendency for larger decreases for Scrambled condition in both hemispheres, and the Low AQ group showed a tendency to have smaller decreases when compared to other groups (**: $p \leq 0.01$).

8.3.6. Paired samples t-test

Paired-sample t-tests were applied at each group to further analyse data, particularly with respect to the Circle condition that was not included in the previous analysis. Repeated measures ANOVA were also applied to all 4 conditions, to include Circle condition with three main conditions, but no group differences were found. Paired-samples t-test will be applied for each group to show which main conditions show significant differences when compared to Circle condition, taken here as a "baseline condition". Circle condition, which was used for comparison, was also baseline normalised. Data will be presented comparing three groups (Low AQ, High AQ and ASD Relatives groups), and when important, AQ groups will be collapsed to create the Non-Relatives group to compare it with ASD Relatives group. This comparison, although important, must be taken with caution because the group creating the comparison group of typically developing individuals with non-first-degree relatives with autism have only those who fall into extremes of autistic tendency.

8.3.7. Beta power decreases over M1

The Low AQ group showed larger beta decreases for Circle condition when compared to Direction (t(12) = 2.61, p = 0.02) and marginally to Emotion (t = 2.11, p = 0.06) conditions, with differences found only in the left hemisphere. The High AQ group showed larger decreases for Circle condition when compared to Direction (LH, t = 2.76, p = 0.02) and Emotion condition (for both hemispheres, t > 3.1, p < 0.01). In the High AQ group, some marginally larger decreases were found for Scrambled when compared to Direction and Emotion conditions (both, p = 0.07), also in the left hemisphere. The Relatives group showed larger decreases for Circle compared to Direction condition in the right hemisphere (t = 2.87, p = 0.02). Only this group showed differences between Direction and Emotion, with larger decreases for Emotion in the right hemisphere (t = 2.27, p = 0.05), but did not show differences between Circle and Emotion. (**Figure 8-12 & 8-13**).

When AQ groups were collapsed into the Non-Relatives group, results showed larger decreases for Circle compared to Direction and Emotion conditions in both hemispheres (all condition comparisons, p < 0.03 for all condition cmparisons bilaterally, and p = 0.05 when comparing Circle with Emotion in the right hemisphere). These results may be summarised as showing the important differences between Relatives and Non-Relatives groups with the Relatives group not showing differentiation between Circle (as a baseline) and Emotion condition. **(Figure 8-14 & 8-15).**

The analysis showed an unexpected direction of relationship for these comparisons, namely, higher suppression for the Circle condition compared to other conditions. Although for Circle condition differences were found only in comparison with biological motion conditions (Direction and Emotion condition) in the left hemisphere, and predominantly in two AQ groups, significant differences between the two non-biological conditions were found only in the Relatives group. It is possible that higher suppression for this condition is influenced by the nature of the task. Participants were required to recognise the Direction of the moving Circle, and not just passively observe the stimuli. In comparison, the non-biological motion Scrambled condition required differentiation of biological vs non-biological motion in the same trial block.
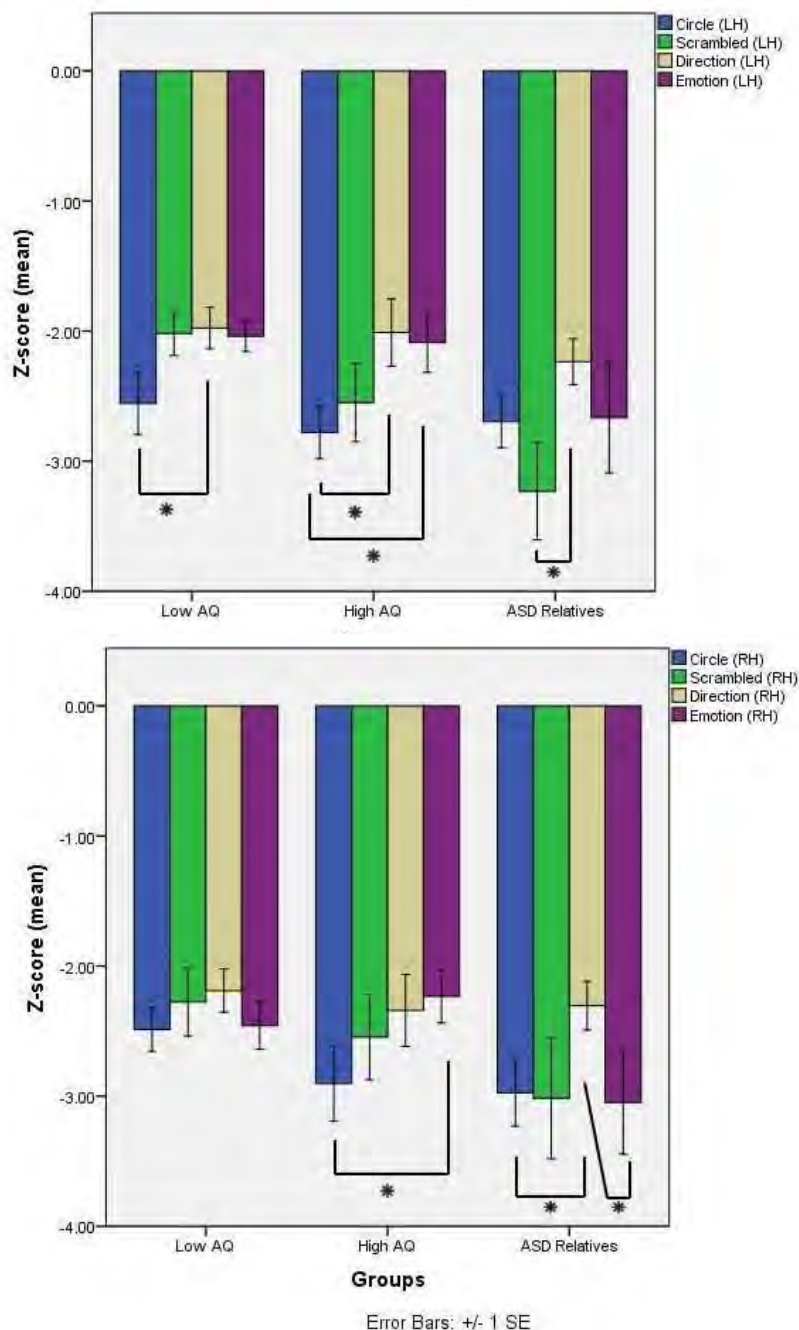
Figure 8-12 & 8-13: Beta decreases over M1 (for left and right hemispheres) for each group. In the left hemisphere, larger beta decreases were found for Circle compared to Direction condition in the Low AQ group and for circle compared to both biological motion conditions (Direction and Emotion) in the High AQ group. Larger decreases were found for Scrambled compared to Direction condition for the ASD Relatives group. In the right hemisphere only the High AQ group showed differences between Circle and Emotion conditions, whereas for the Relatives group Direction condition showed smaller decreases when compared to Circle and Emotion conditions. (* - $p \leq 0.05$)
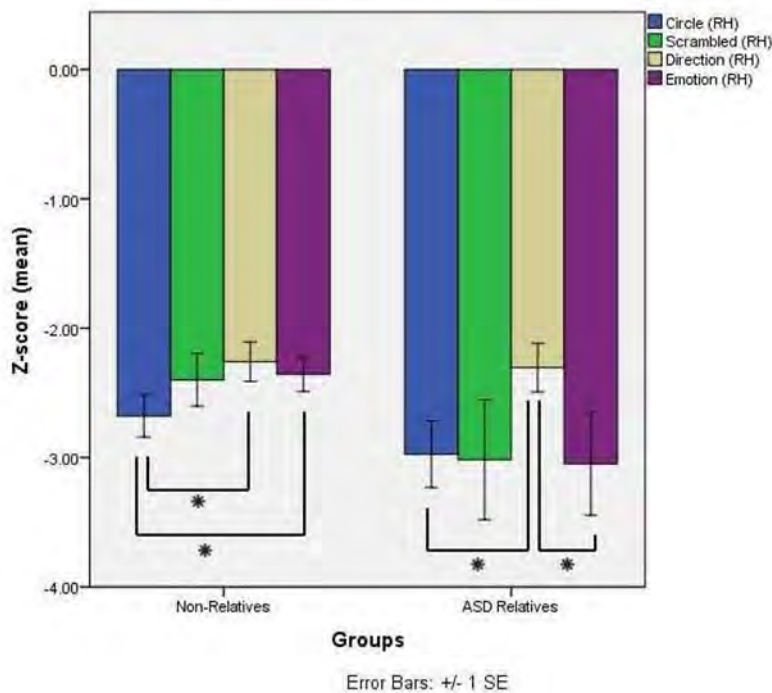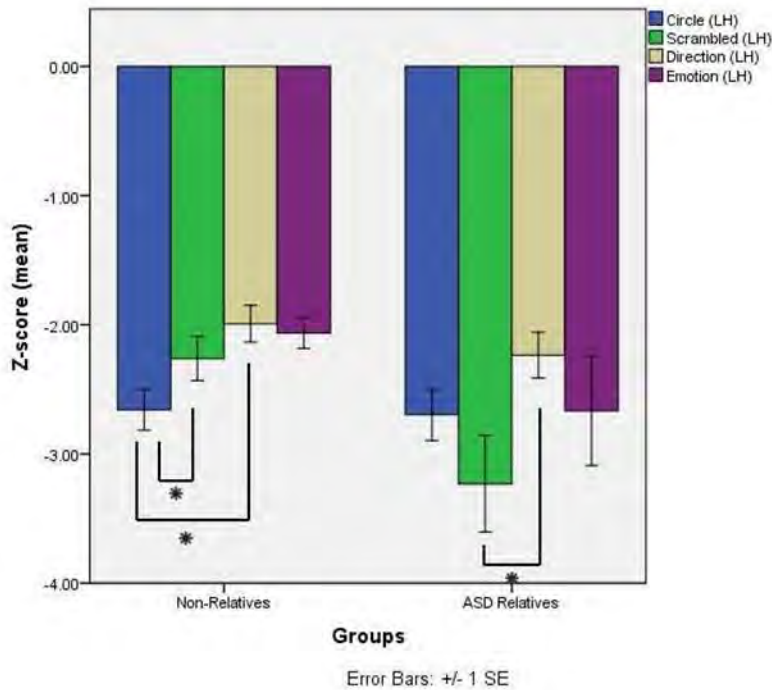
Figure 8-14 & 8-15: Beta decreases over M1 for left and right hemisphere (Non-Relatives vs. ASD Relatives group). In the right hemisphere, differences between Circle and Direction conditions were found for both groups, with differences between two non-biological conditions (Circle and Scrambled) found only in the Non-Relatives group. In the right hemisphere, only in the Non-Relatives group differences between Circle and Emotion conditions were found, with this group showing significant differences between Circle (as a baseline) and both biological motion condition. As the Relatives group also showed differences between Circle and Direction conditions, absent differentiation between Circle and Emotion is an important difference between groups. (* - $p \leq 0.05$)

8.3.8. Beta power decreases over S1

The Low AQ group showed larger beta decreases for the Circle condition when compared to Scrambled and Direction conditions (both in LH with $t > 2.5$, $p < 0.03$), while compared to the Emotion condition it was not significant ($t = 1.92$, $p = 0.08$). Similar to the Low AQ group, the High AQ group showed a larger decrease for Circle than Direction condition (in LH, $t = 2.84$, $p = 0.02$), and also a tendency for larger decrease for Circle compared to Emotion condition (LH, $t = 1.97$, $p = 0.07$; RH, $t = 2.19$, $p = 0.05$). For the Relatives group, larger beta decreases were found for Scrambled than Direction condition (LH, $t = 2.72$, $p = 0.02$), Emotion than Direction condition (LH, $t = 2.44$, $p = 0.05$), and Circle larger than Direction condition (LH, 3.44, $p = 0.01$), again with statistically significant differences found only in the left hemisphere. (**Figure 8-16 & 8-17**)

When AQ groups were collapsed into the Non-Relatives group, there was larger decrease for Circle than Direction condition (LH, $t = 4.02$, $p = 0.001$), and for Circle compared to Emotion condition (LH, $t = 2.81$, $p = 0.01$; RH, $t = 2.58$, $p = 0.02$). (**Figure 8-18 & 8-19**)

8.3.9. Beta band decreases over pars opercularis

The paired samples t-test for the Low AQ group showed larger decreases for the Circle condition compared to Scrambled ($t = 4.73$, $p = 0.001$) and Emotion ($t = 4.32$, $p = 0.001$) conditions in the left hemisphere, and the Direction condition in both hemispheres (both, $t > 2.5$, $p < 0.03$). For the High AQ group, a larger decrease for the Circle condition was found when compared to the Emotion condition in both hemispheres (LH, $t = 2.26$, $p = 0.05$; RH, $t = 3.09$, $p = 0.01$). For the Relatives group, when compared with the Circle condition, larger decreases were found for the Direction condition in the left hemisphere ($t = 2.75$, $p = 0.02$). Only this group showed differences between main conditions, showing larger decreases for Scrambled than Direction condition ($t = 2.27$, $p = 0.05$), and for Emotion than Direction condition ($t = 2.97$, $p = 0.02$), both in the left hemisphere only. (**Figure 8-20 & 8-21**).

Examining the Non-Relatives group, results revealed larger decreases for Circle compared to Scrambled ($t = 2.82$, $p = 0.01$) and Direction ($t = 2.36$, $p = 0.03$) conditions in the left hemispehre, and for Emotion condition in both hemispheres (both, $t > 3.3$, $p < 0.01$). (**Figure 8-22 & 8-23**).
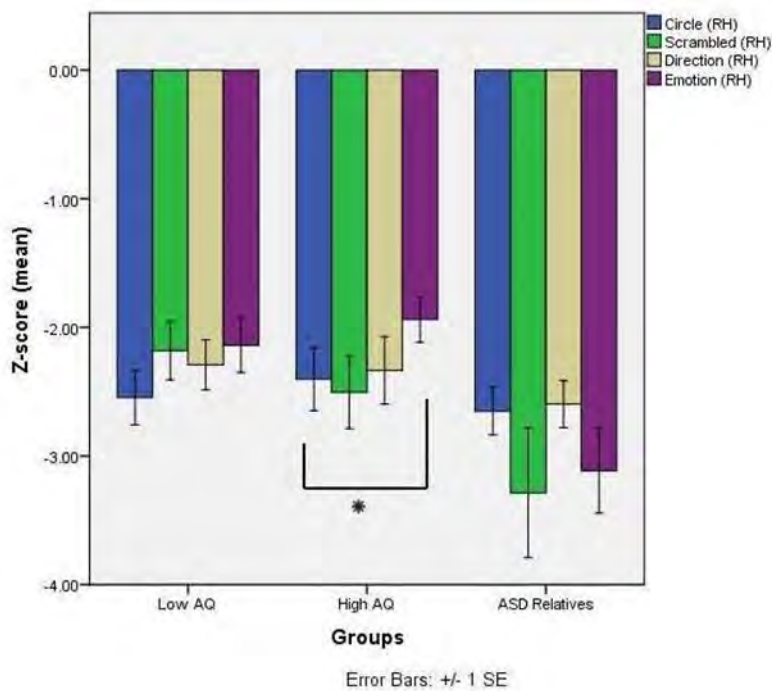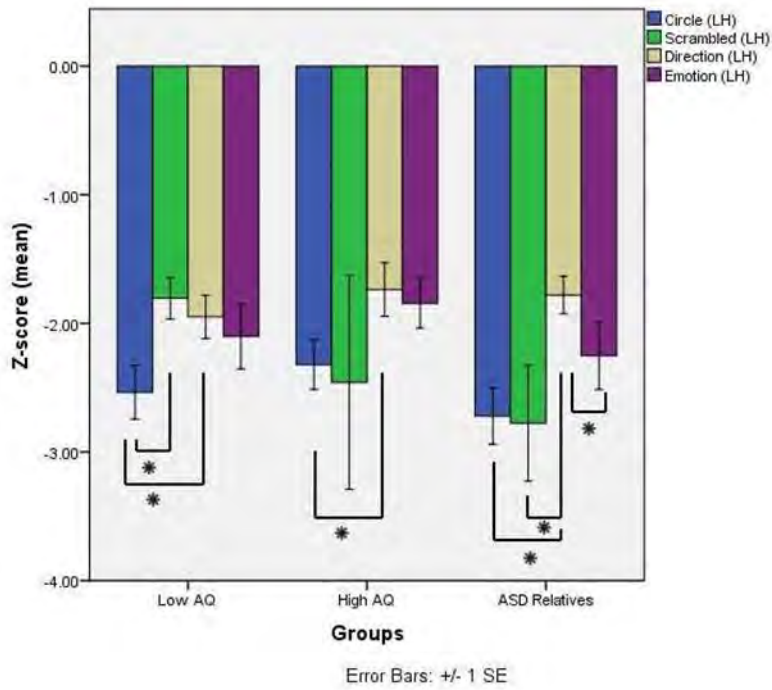
Figure 8-16 & 8-17: Beta band decreases over S1 in the left hemisphere showed significant differences between Circle condition and Direction condition in all groups. The Relatives group showed smaller decreases for Direction condition compared to other conditions. In the right hemisphere, difference between Circle and Emotion condition was found only in the High AQ group.

(* - $p \leq 0.05$)
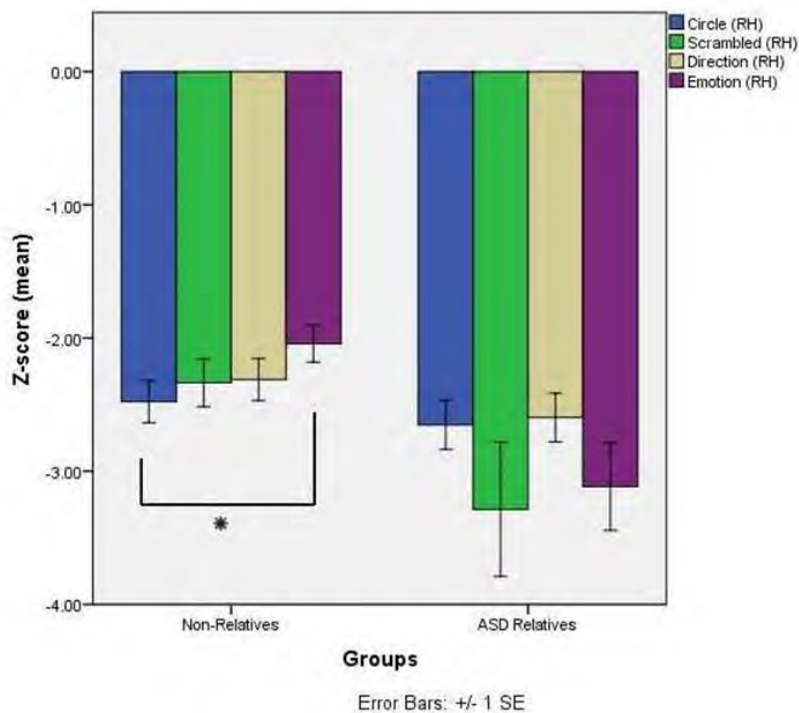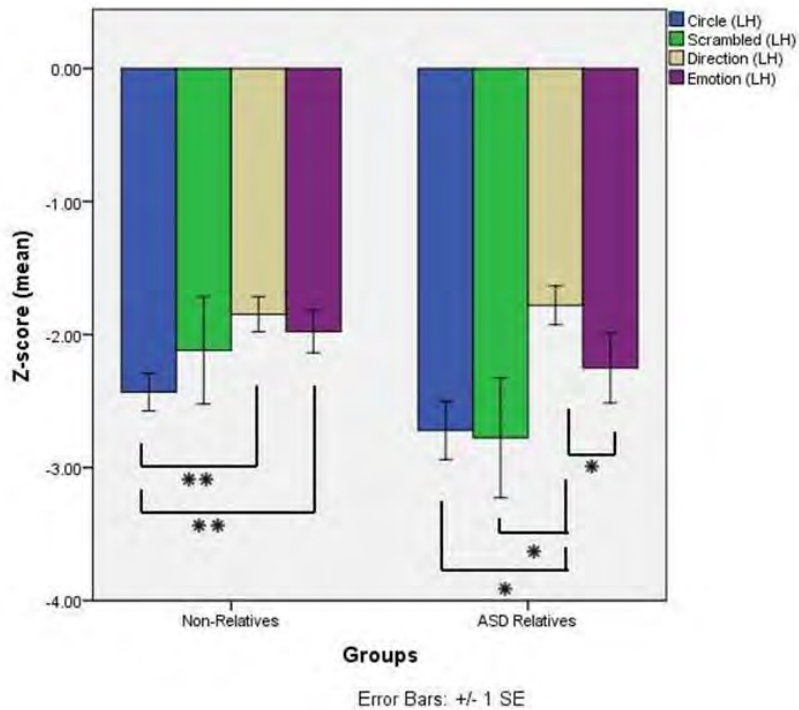
Figure 8-18 & 8-19. Beta decreases over S1, when comparing the Non-Relatives vs ASD Relatives groups indicated significant differences between Circle and both biological motion conditions (Direction and Emotion). As the Relatives group did no show significant differences between Circle and Emotion condition, it is considered an important difference between groups, with the Relatives group showing less sensitivity for biological motion stimuli showing mentalising characteristics.

(*- $p \leq 0.05$; **- $p \leq 0.01$).
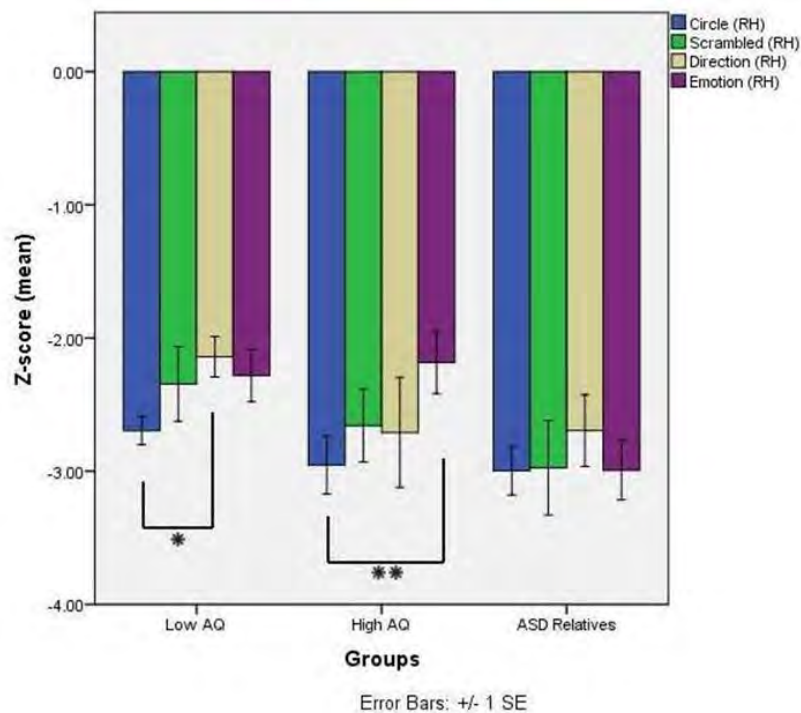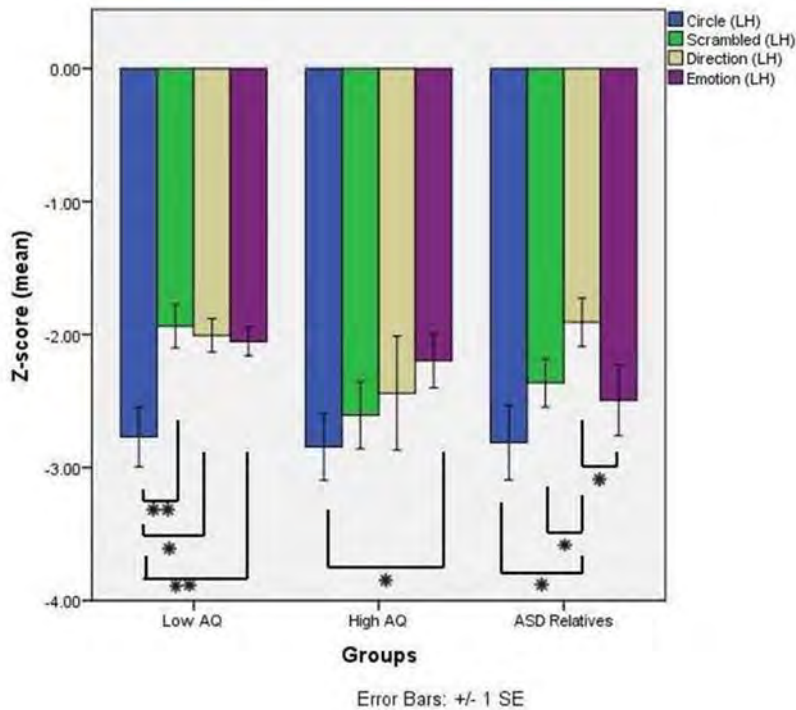
Figure 8-20 & 8-21. Beta decreases over pars opercularis in the left hemisphere indicates significantly larger decreases for the Circle condition when compared to all other condition in the Low AQ group, but only when compared to Emotion condition in the High AQ group. The Relatives group did not show differences between Circle and Emotion condition, similar to previously analysed regions, and the main effect in this group indicated smaller decreses for Direction condition when compared to other conditions. In the right hemisphere, difference between Circle and Direction conditions was found in the Low AQ group, and between Circle and Emotion condition in the High AQ group. No significant differences were found in the Relatives group. (*- $p \leq 0.05$; **- $p \leq 0.01$)
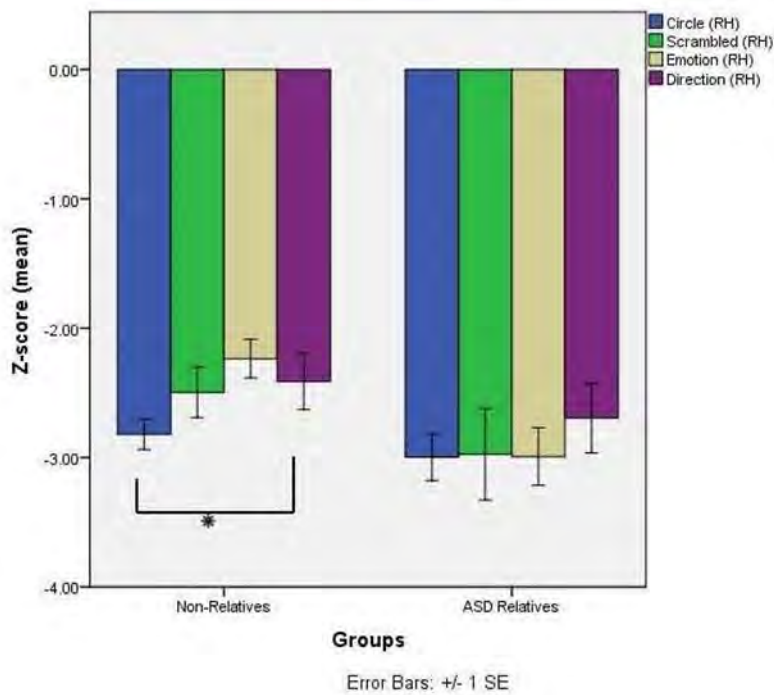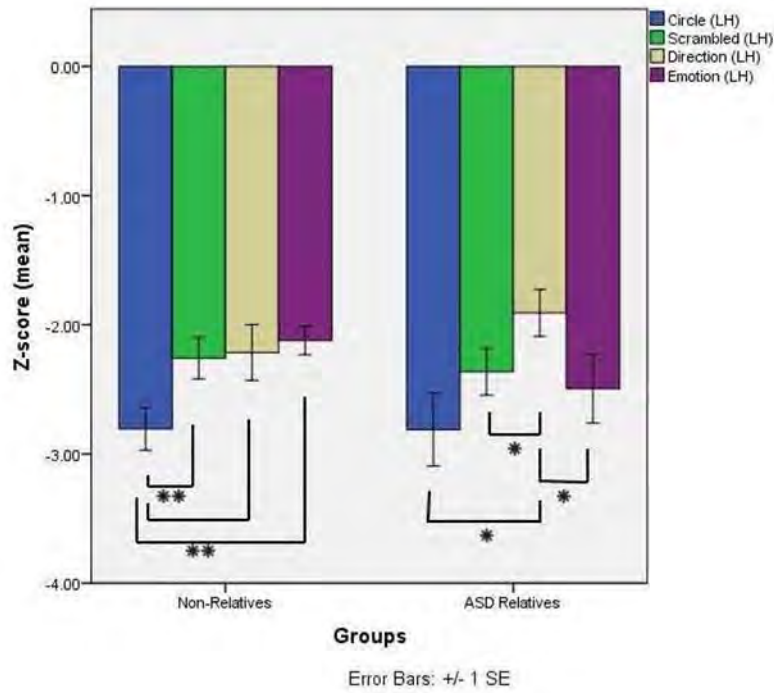
Figure 8-22 & 8-23. When analysing the Non-Relatives group, significant differences were observed between Circle condition and all other conditions in the left hemisphere, and Circle and Emotion conditions in the righ hemisphere. It can be stated that an important difference between the Non-Relatives and ASD Relatives groups is an absent differentiation between Circle and Emotion condition for the Realtives group in both hemispheres, when compared to the Non-Relative group.
(*- p ≤ 0.05; **- p ≤ 0.01)

8.3.10. Beta power decrease over STS

Paired samples t-test for the Low AQ group showed larger decreases for Emotion when compared to Scrambled condition (RH, t = 2.19, p = 0.05), for Circle when compared to Scrambled condition (both hemispheres, t > 2.7, p < 0.01) and for Circle compared to Direction condition (LH, t = 4.03, p = 0.002). Nothing significant was found for the High AQ group. For the Relatives group, there were larger decreases for Emotion compared to Scrambled condition (RH, 3.24, p = 0.01), for Emotion compared to Direction condition (LH, 4.63, p = 0.001), Circle compared to Direction condition (LH, t = 2.94, p = 0.02) (**Figure 8-24 & 8-25**).

When looking at the Non-Relatives group, the only significant difference found was larger decreases for Circle than Scrambled condition in the right hemisphere (t = 2.24, p = 0.04), indicating that more important differences were found when examining AQ groups, than comparing the Relatives vs Non-Relatives groups. (**Figure 8-26 & 8-27**).

8.3.11. Alpha power decrease over S1

The paired t-test showed that for the Low AQ group, larger decreases were found for Circle compared to Scrambled (t(12) = 2.21, p = 0.001), Direction (t = 2.93, p = 0.01) and Emotion (t = 3.29, p = 0.01) conditions in the left hemisphere. A similar effect was found for the High AQ group, although in smaller measure for Circle vs Emotion condition differences (t = 2.72, p = 0.02; t = 2.58, p = 0.03; t = 2.11, p = 0.06, for larger Circle compared to Scrambled, Direction and Emotion conditions in the left hemisphere, for each comparison respectively). For the Relatives group, only marginally larger decreases for Scrambled compared to Circle conditions was found in the right hemisphere (t = 2.25, p = 0.05) (**Figure 8-28 & 8-29**).

Collapsing AQ groups into the Non-Relative group showed significant decreases for Circle compared to three main conditions in the left hemisphere (for all conditions, p < 0.01). (**Figure 8-30 & 8-31**).
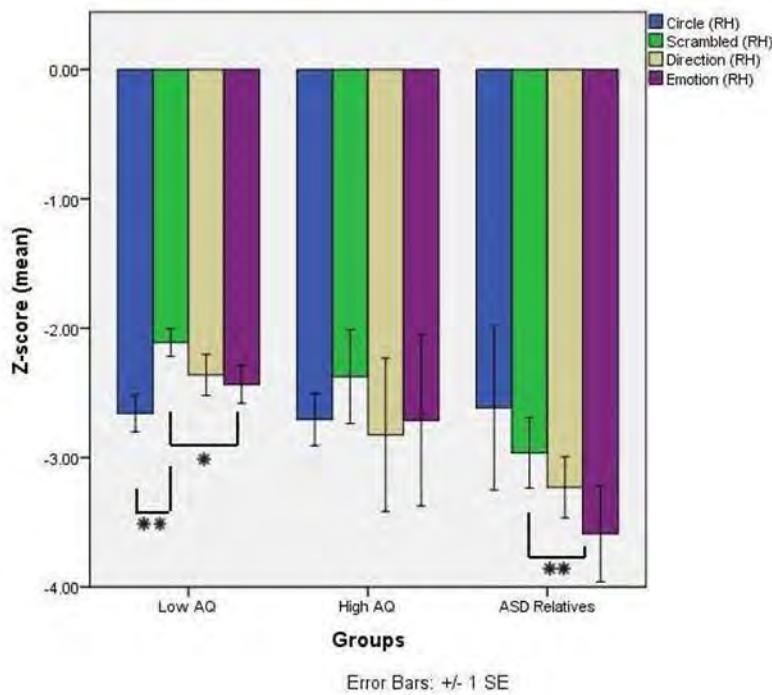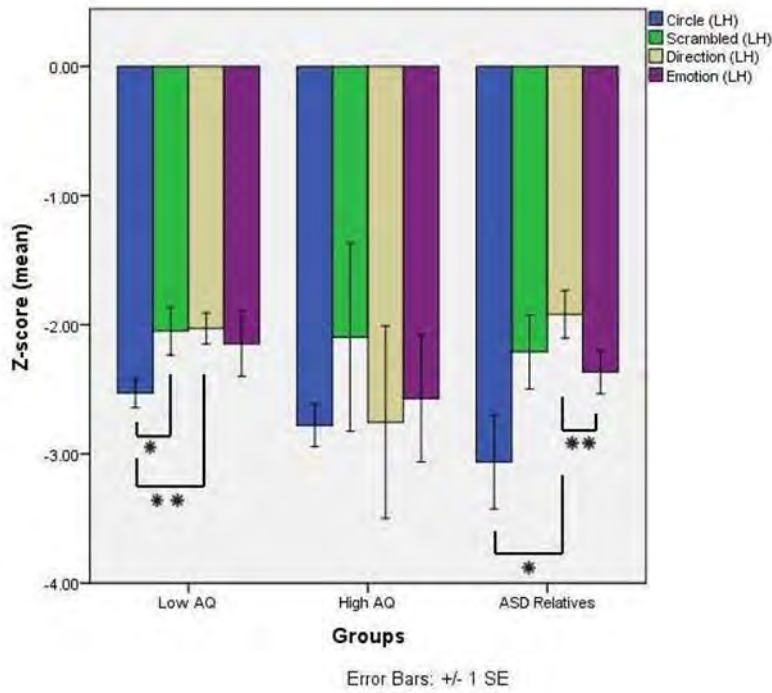
Figure 8-24 & 8-25. Beta decrease over STS shows that in the left hemisphere, there was difference between Circle compared to Scrambled and Direction conditions in the Low AQ group, and smaller decreases for Direction when compared to Circle and Emotion conditions in the Relatives group. In the right hemisphere, both the Low AQ group and the Relatives group showed larger decreases for emotion when compared to scrambled condition. This effect is important because it was not observed at other regions and seems important in showing larger Emotion decreases compared to other non-biological motion conditions. No significant differences between conditions were found for the High AQ group, showing more similarities between the Low AQ and the Non Relatives groups than between the two AQ groups (as the Non-Relatives).

(*- p ≤ 0.05; **- p ≤ 0.01)

Error Bars: +/- 1 SE
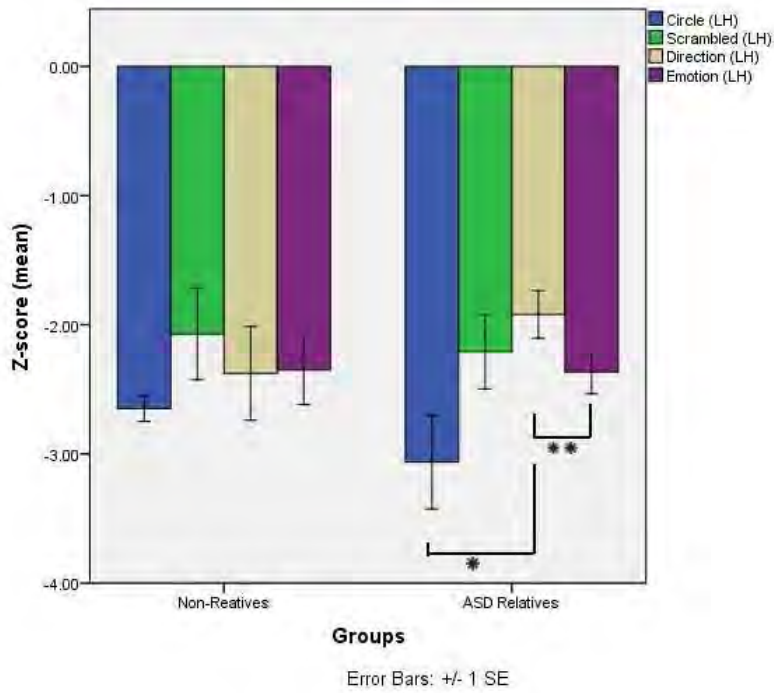
Figure 8-26 & 8-27. When collapsing AQ groups to create the Non-Relatives group, beta decrease over STS in the right hemisphere did not show any differences between conditions, indicating differences only for the Relatives group. In the right hemisphere, only the Relatives group showed significant differentiation between Scrambled and Emotion condition.

(*- p $\leq$ 0.05; **- p $\leq$ 0.01)

Error Bars: +/- 1 SE
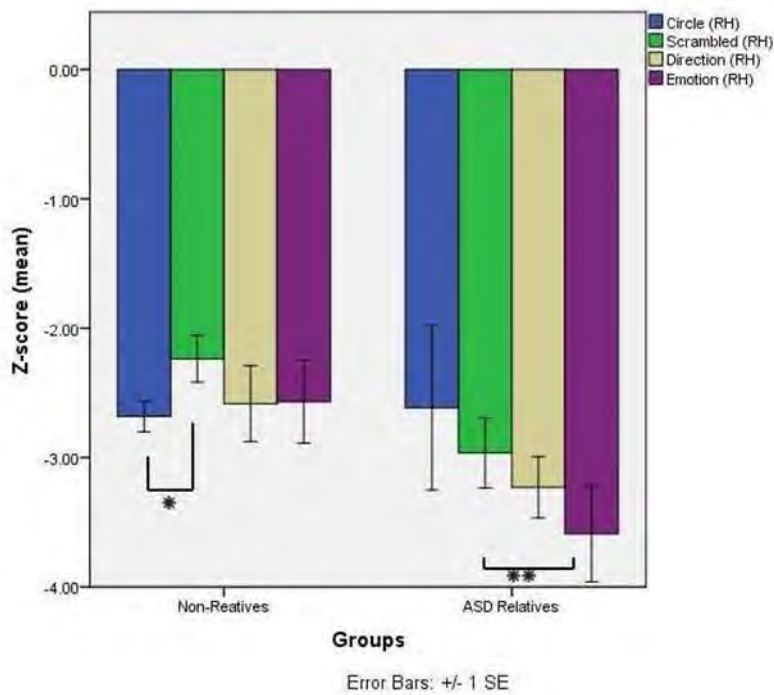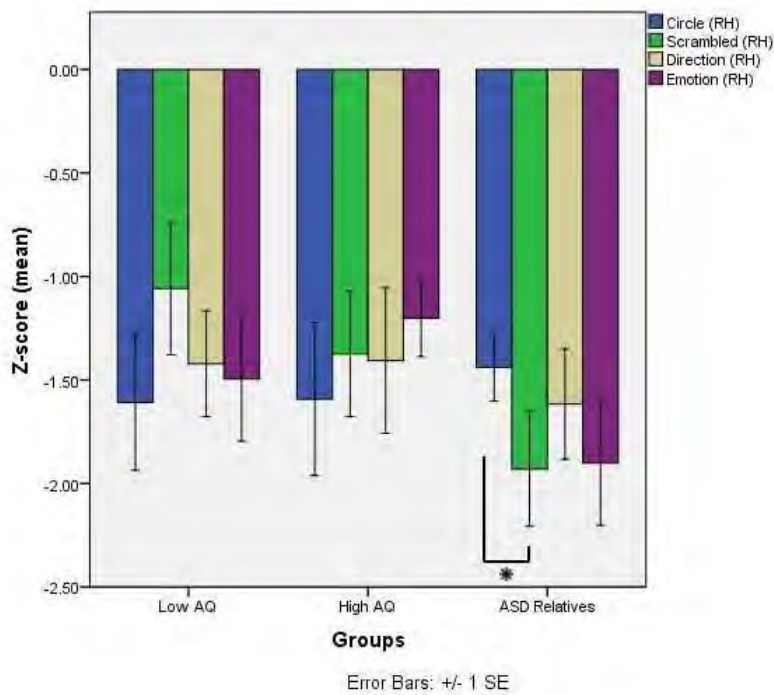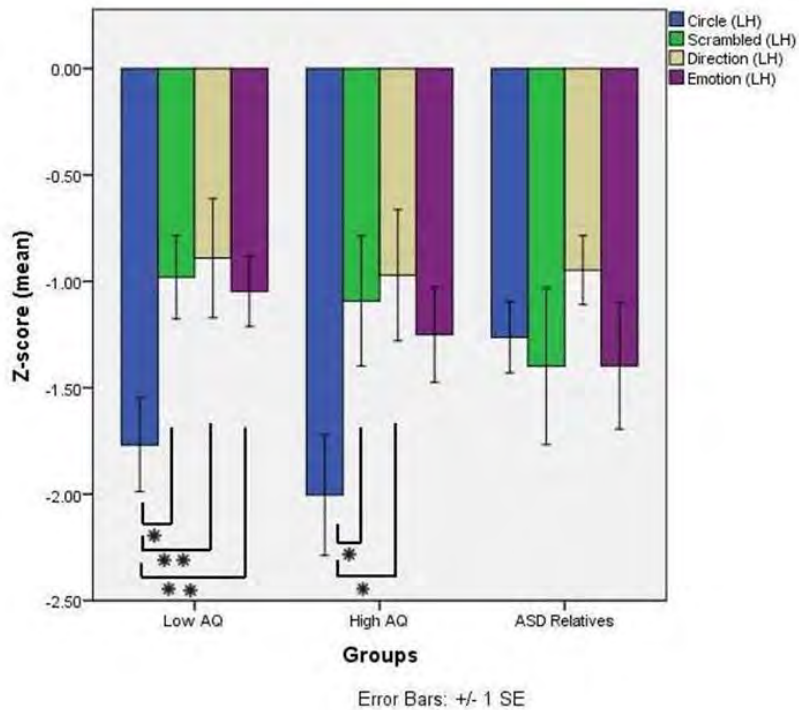
Figure 8-28 & 8-29. Alpha decrease over S1 showed all important condition differences to be in the left hemisphere, with larger decreases for Circle than all main conditions in the Low AQ group, and for Circle compared to Scrambled and Direction conditions in the High AQ group. Nothing significant was found for the Relatives group in the left hemisphere, and only this group showed differences between the two non-biological conditions in the right hemisphere.

(*- p ≤ 0.05; **- p ≤ 0.01)
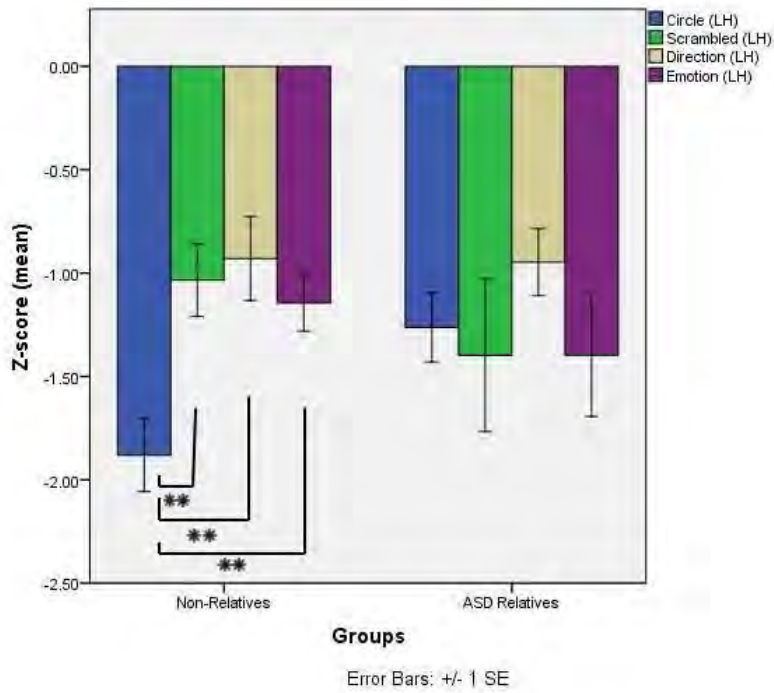
Figure 8-30 8-31. Alpha decreases over S1 (Non-Relatives and ASD Relatives groups). When the AQ groups were collapsed to create the Non-Relatives group, results showed significant differences between Circle and other conditions, showing differences of this group with the Relatives group.

(*- $p \le 0.05$; **- $p \le 0.01$)

8.3.12. Correlations

Non-parametric Spearman one-tailed correlations across all groups and also for each group was performed to examine correlation between the main measures and beta and alpha power decreases over analysed regions and for each condition. An additional correlation analysis was also performed for Age and Sex.

8.3.12.1. Correlations across all participants

AQ scores correlated positively with beta decreases over M1 for the Emotion condition (RH, r = .29, p = 0.05), and negatively with the Circle condition in both hemispheres (LH: r = -.39, RH: r = -.395, for both hemispheres p < 0.04). Over pars opercularis, AQ scores correlated negatively with both non-biological conditions, that is with the Scrambled in the left hemisphere (r = -.616, p = 0.029) and with the Circle in the right hemisphere (r = -.604, p = p = 0.032). Also, a negative correlation was found between AQ and Scrambled (both hemispheres, p < 0.01) and Emotion conditions (both hemispheres, p < 0.02) for alpha decreases over S1. Results show no correlation between AQ scores and any of condition for beta decreases over S1 and STS.

EQ scores correlated negatively with the Emotion condition in both hemispheres (LH: r = -.31, p = 0.04; RH: r = -.39, p = 0.01), and positively with the Circle condition also in both hemispheres (both p = 0.04) for beta decreases over M1. Over S1, EQ scores correlated negatively with Direction condition (RH, r = -.31, p = 0.04). For alpha decrease over S1, a negative correlation was found between EQ scores and Emotion condition (both hemispheres, both r = -.31, p = 0.04).

SQ scores correlated negatively with Direction condition (LH, r = -.3, p = 0.04), and positively with Emotion condition (LH, r = .34, p = 0.02) for beta decrease over M1. Over pars opercularis, Scrambled condition in both hemispheres correlated positively with SQ scores (both hemishpheres, p < 0.05; LH, r = -.558; RH, r = -.657). Over STS, a negative correlation was found between SQ scores and Circle condition (RH, r = -.3, p = 0.04).

These results indicate that over M1, Emotion condition showed correlation with all three measures, indicating that larger Emotion condition decreases may be a result of smaller AQ and SQ scores, but larger EQ scores. It is also interesting that EQ correlated negatively with Emotion condition in both hemispheres for alpha and beta decreases over sensorimotor cortex, an area considered to be an index of MNS activity, indicating that larger empathy level is predictive of larger decreases for Emotion condition at those regions.

Correlation analysis across all groups suggest that beta decreases over M1 most probably can be explained by some interaction of subjects' level of three important measures – AQ, EQ and SQ scores, rather than just one of them. Correlations over this region are particularly important because they show direct correlation between EQ scores and Emotion condition. Larger AQ and SQ scores were correlated with smaller suppression for Emotion condition, whereas larger EQ scores were correlated with larger decreases for Emotion condition. An opposite interaction was found for the Circle condition, with a larger decrease for the Circle condition with larger AQ and smaller EQ scores. Only SQ scores correlated negatively with Direction condition.

An additional correlation between **Age** and conditions was performed and results revealed a negative correlation between Age and Emotion condition for beta decreases over M1 in both hemispheres (LH, $r = -.36$/RH, $r = -.35$, both $p = 0.02$), S1 (LH, $r = -.3$, $p = 0.05$) and pars opercularis (LH, $r = -.301$, $p = .04$). Over S1, Age also correalted negatively with Scrambled condition (LH, $r = -.34$, $p = 0.03$).

These results indicated that older participants show larger decreases for Emotion condition. There has been evidence of reduced sensitvity to motion in older participants (e.g., Billino, Bremmer, & Gegenfurtner, 2008; Gilmore, Wenk, Naylor, & Stuve, 1992; Trick & Silverman 1991), including difficulties in detecting motion direction (Ball & Sekuler 1986; Bennett, Sekuler, & Sekuler, 2007). However, there are not conclusive results about the effect age has on biological-motion perception (Billino et al., 2008; Norman, Payton, Long, & Hawk, 2004; Pilz, Bennett, & Sekuler, 2010). Recently, Legault, Troje and Faubert (2012) showed age-related deficits for biological motion perception in older adults, and also showed that, in order to integrate biological-mtion information, this group required bigger distance in virtual space between themselves and the point-light walker. Research on biological motion that examined the effects of age mostly suggested that age-related effects on biological motion can be due to perceptual differences, as older participants show a local-processing bias and lower performance on biological motion decoding, although the authors suggested that other factors may be more predictive in explaining the role of age in social perception (Insch, Bull, Phillips, Allen, & Slessor, 2012).

8.3.12.2. Correlations for groups

A detailed correlation analysis for each group is shown in **Table 8-2**. Several important findings will be discussed. The ASD Relatives group showed correlation between

Age and beta decreases for Direction condition over all regions, predominantly in the right hemisphere. This was not found for alpha decreases over S1. This finding is important because half of the participants in the Relatives group were older than other participants in this study. However, interaction between Age and Direction condition for beta band shows that there are differences in orientation of this interaction with negative correlation over M1 and S1 and positive over pars opercularis and STS. The ASD group showed significantly smaller decreases for Direction condition when compare to Emotion and Scrambled condition for most regions in the left hemisphere (correlation in the left hemisphere was significant only with Opercular region), and this effect was not seen for alpha decreases over S1.

Another important findings about correlation analysis is that correlation results for EQ scores were found only in the Low AQ group for beta decreases over M1 and S1 (limiting this effect only over sensorimotor region), with positive correlation between EQ scores and beta decreases for Direction condition. This result indicates that larger EQ scores predict smaller beta decreases for Direction condition in the left hemisphere. Previous analysis indicated smaller decreases for Direction condition in this group when compared to Circle condition in the left hemisphere (although the same effect was also found for other groups, but it seems that only the Low AQ showed a correlation with empathy level). In the Low AQ group, analysis over M1 also showed a negative correlation between Direction condition in the left hemisphere and AQ scores, and the opposite effect than that found for correlation with EQ scores.

Concerning SQ scores, an interesting finding shows that all three groups showed correlation between SQ scores and Emotion condition in the left hemisphere for beta decrease over STS. However, the Low and High AQ groups showed positive correlation, while negative correlation was found for the Relatives group. These results would indicate that larger SQ scores would predict smaller decreases for Emotion condition, and it was previously found that the Low AQ group has smaller SQ scores, and the High AQ group has larger SQ scores, and this would indicate larger Emotion decrease for the Low AQ group. On the other hand, the opposite effect found for the Relatives group would show that larger SQ scores in this group predict larger Emotion decreases.

Table 8-2: Correlation analysis for each group.

Correlations for Beta band

Spearman's rho		Scrambled (LH)	Scrambled (RH)	Direction (LH)	Direction (RH)	Emotion (LH)	Emotion (RH)	Circle (LH)	Circle (RH)
AQ	Low AQ			(M1) R = -.52* (STS) r = -.63**		(S1) r = -.5* (OP) r = -.83**	(STS) r = -.59*	(M1) r = -.48* (OP) r = -.57*	(M1) r = -.63** (S1) r = -.71**
	High AQ		(M1) r = -.62* (S1) r = .73**				(STS) r = .54*		
	Relatives		(OP) r = -.62*					(OP) r = -.6*	
EQ	Low AQ			(M1) r = .54* (S1) r = .6					
	High AQ								
	Relatives								
SQ	Low AQ		(STS) r = -.64**			(M1) r = .55 (STS) r = .49*			(OP) r = -.51*
	High AQ	(S1) r = -.6* (OP) r = -.56*	(S1) r = -.6 (OP) r = -.66		(S1) r = -.55*	(STS) r = .5*		(S1) r = -.56*	
	Relatives		(STS) r = -.5*			(STS) r = -.63**			
AGE	Low AQ	(M1) r = -.55* (OP) r = -.71**	(STS) r = -.5*						
	High AQ					(OP) r = -.61*			
	Relatives			(OP) r = .83**	(M1) r = -.56* (S1) r = -.67* (OP) r = .5* (STS) r = .59*				

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).

Correlations for alpha power decreases over S1

Groups

The main findings of correlation analysis for alpha power decreases over S1 shows that correlation with Emotion condition was found only for the High AQ group, with a positive correlation with SQ scores, and a negative correlation with EQ scores. These results would mean that reduced decreases for emotional point light displays may be due to their larger SQ scores and smaller EQ scores. Correlation for each group is shown in **Table 8-3.**

Table 8-3. Correlations for alpha band (over S1)

Spearman's rho		Scrambled (LH)	Scrambled (RH)	Direction (LH)	Direction (RH)	Emotion (LH)	Emotion (RH)	Circle (LH)	Circle (RH)
							Correlations for Alpha band (S1)		
AQ	Low AQ								
	High AQ	r = 0.63*							
	Relatives							r = -0.63*	
EQ	Low AQ								
	High AQ						r = -0.63*		
	Relatives								
SQ	Low AQ								
	High AQ	r = 0.54*				r = 0.58*			
	Relatives			r = -0.58*				r = -0.63*	
AGE	Low AQ								
	High AQ								
	Relatives								

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed)

Figure 8-32, 8-33, 8-34:

Time frequency maps (TFM) for beta band activity over regions and for each group, showing activity for Emotion condition only. An example of TFMs shows strongest beta decreases over STS regions. Also, the Relatives group showed stronger decreases compared to other groups. (Scales on the right shows baseline normalized data, represented as mean z-score, and all data are shown from 0 to 3s).

Emotion Condition
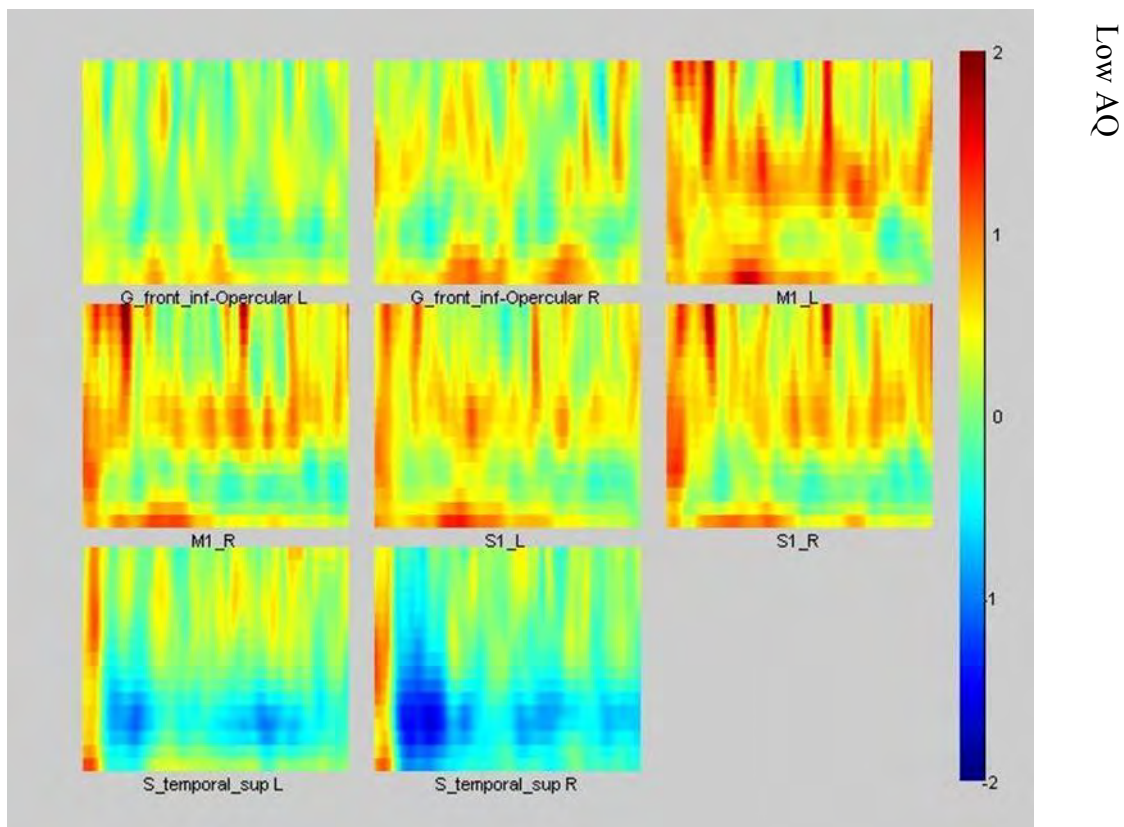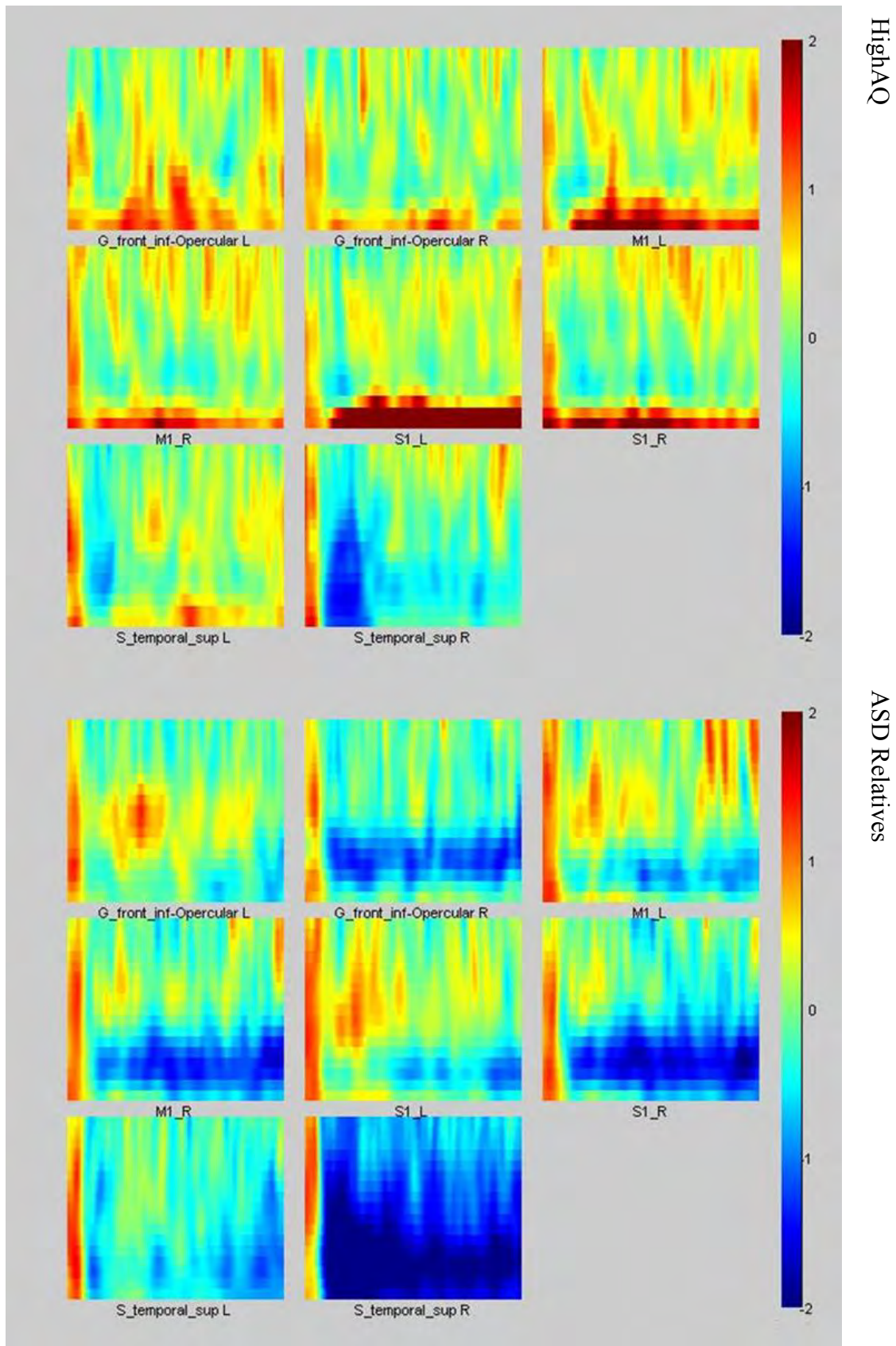
Figure 8-35.

Beta power (baseline normalised, showing mean z-score results) for each Emotion condition and group (first order gradiometers only).
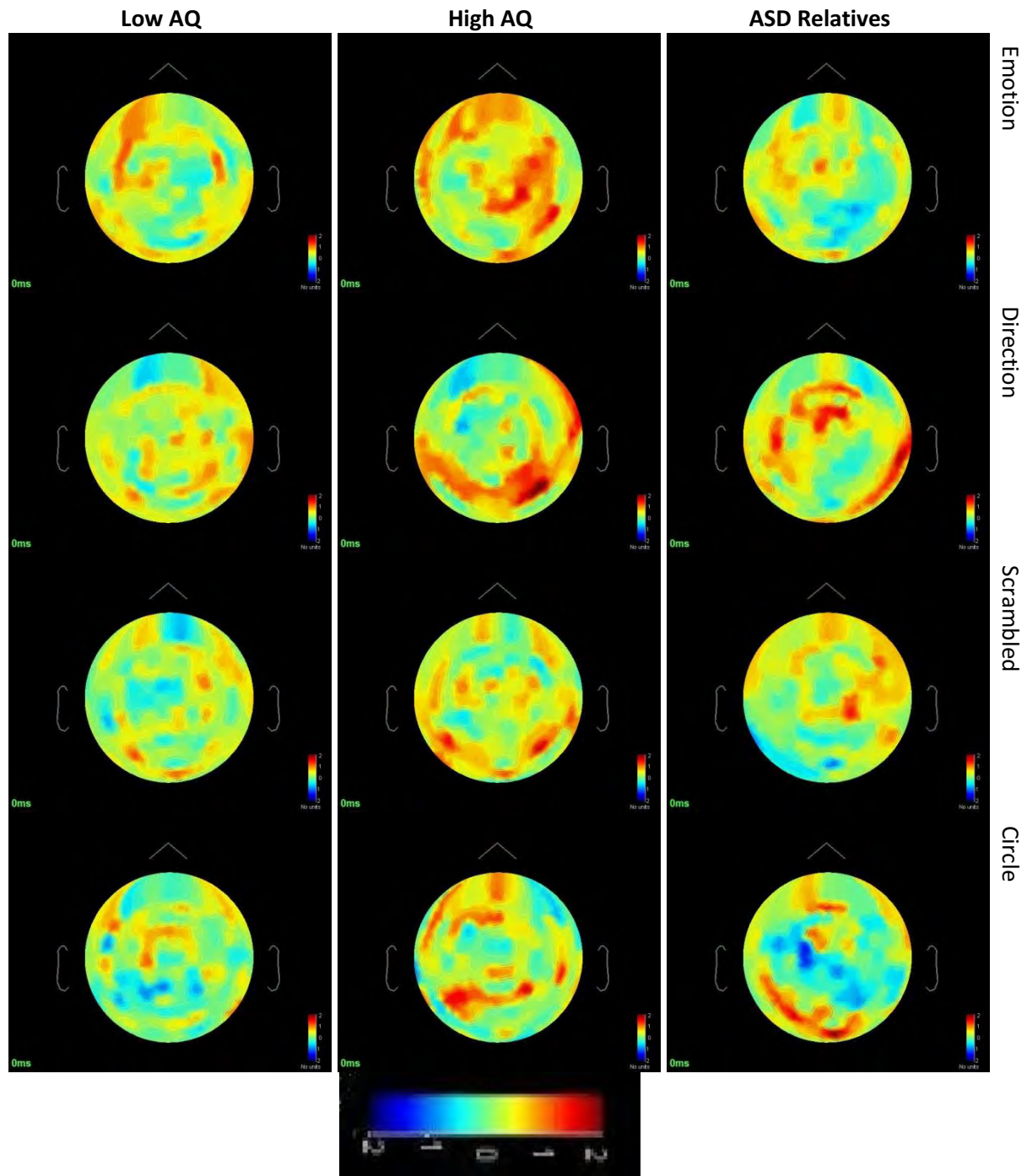
Figure 8-36: TFR Analysis

Spectral data (8–60Hz) are averaged across all sensors for each condition. Data in each plot are normalised to a baseline period (not shown, data are presented from 0 to 3 s). Scale on the right shows mean z-scores. Hot colours indicate increased power and cold colours indicate decreased power. Results show a larger power decrease (as seen in blue) around 20 Hz (low beta), and stronger decreases for biological motion conditions (Direction and Emotion) than for non-biological motion conditions (Scrambled and Circle). For the High AQ group, some strong decreases were found in lower frequencies for Emotion condition. The ASD Relatives group showed stronger decrease for three main conditions (Scrambled, Emotion and Direction) when compared with other groups, and power decreases were also seen in lower frequencies (alpha power).
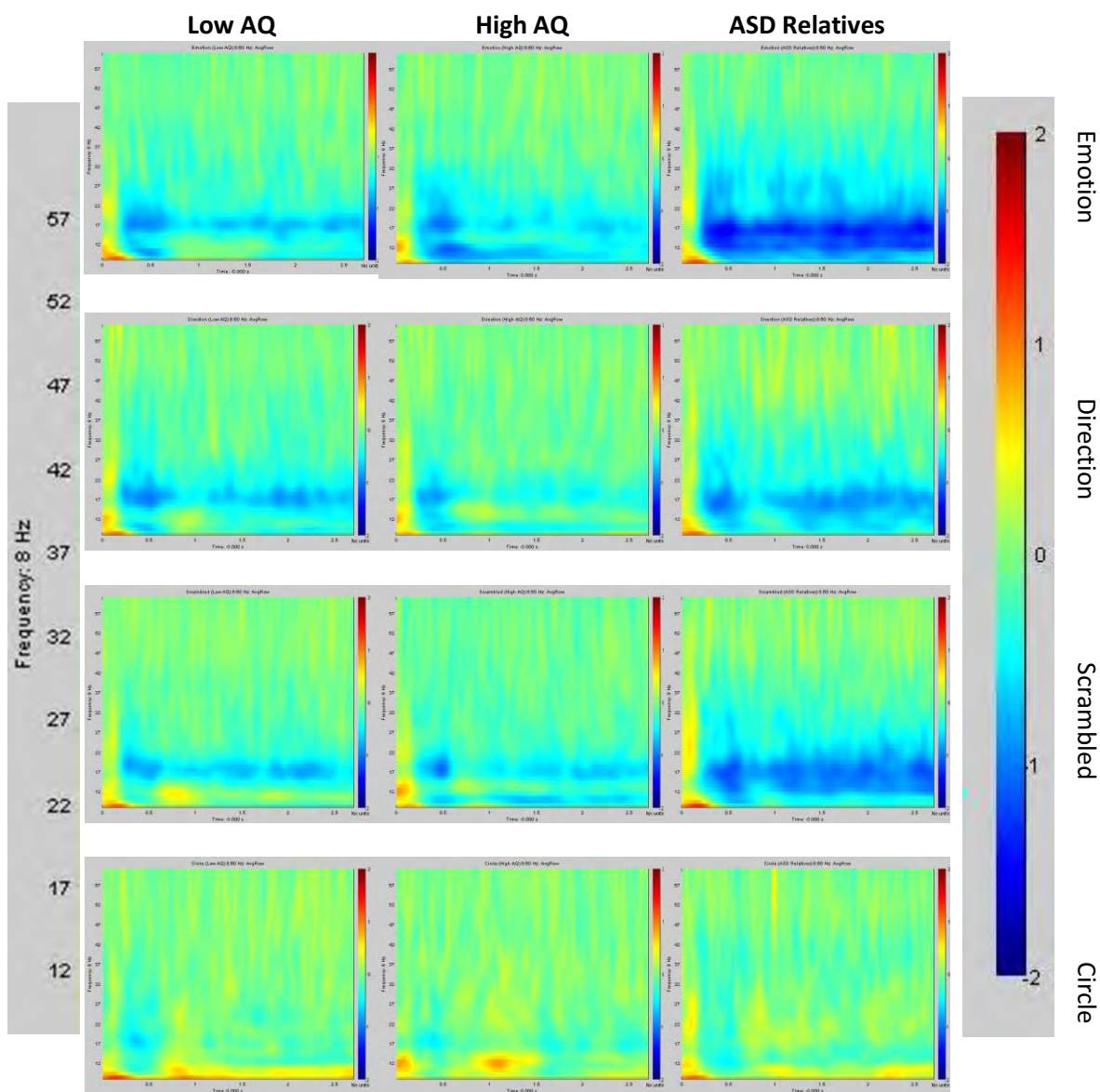
8.4. DISCUSSION

This study examined beta and alpha decreases over several brain regions implicated in the MNS, particularly M1, S1, pars opercularis and STS. Alpha decreases were analysed only over S1. The main aim was to find differences between three main groups – High and Low AQ groups, and the ASD Relatives group, consisting of adult siblings and parents of individuals with autism. The two AQ groups were also collapsed to create the Non-Relatives group, in order to see if any difference can be better explained by AQ differences, or rather by differences between groups consisting of Relatives of ASD individuals or Non-Relatives - that is, typically developing individuals with no ASD relatives. The main prediction of this study is that, based on social difficulties in individuals with autism, the main differences will be expected between Emotion condition, as a highly social condition involving theory of mind reasoning, and non-biological motion conditions, particularly Circle condition that is considered as a baseline.

The results of repeated measure ANOVA over different regions did not find significant group differences for beta decrease over main conditions (Scrambled, Direction and Emotion) over M1, but Condition x group interaction was significant over S1 and pars opercularis regions. However, this effect was mostly expressed as differences between the main three conditions – Scrambled, Direction and Emotion – for the ASD Relatives group. This group showed larger beta decreases in the left hemisphere for Scrambled condition when compared to the Low AQ group, and larger decreases for Emotion condition when compared to the High AQ and also the Low AQ group (in both hemispheres). However, activity in the Relatives group that shows significantly larger decreases for Scrambled condition compared to biological motion conditions indicate that this group reacted more to movement itself, rather than to biological motion.

Although the Circle condition also showed larger power decreases for all groups, this condition differs from other conditions not only in a smaller number of trials, but it also consisted of a task requiring recognising Direction of the moving Circle, whereas the task associated with the Scrambled condition was less pronounced, as it was included in trials together with rare biological motion conditions that required distinguishing these two types of stimuli. Thus, the two non-biological motion conditions have different properties and therefore results may differ when comparing them with biological motion conditions. Larger decreases for the Circle condition probably could be explained by the finding of beta power

attenuation during maximal velocity of stimuli (Press et al., 2011; Stark et al., 2007), as moving dots that created circles may appear faster to an observer than random dots creating human figures or scrambled stimuli. Although this relates mostly to velocity during action execution, some reports suggest that this effect can be also seen during action observation preceding action execution, and suggesting that activity over M1 region is possible based on active inferences (Kilner et al., 2007; Press et al., 2011). Another explanation for larger decreases of the Circle condition may be that it shows easier inferences than in response to other, more complex conditions.

One of the important findings is that beta decreases over M1, S1 and pars opercularis regions showed strong similarities. The most important finding relates to significant differences between Circle and Emotion conditions in the Non-Relatives group, mostly in the right hemisphere. The Relatives group did not show significant differentiation between Circle and Emotion conditions, but this group showed larger decreases for Direction condition. This finding supports the hypothesis of main differences to be found in the more socially salient condition (Emotion). However, when looking at the two AQ groups, data shows that within the Non-Relatives group, it was mostly the High AQ group that showed differentiation between Circle and Emotion conditions. This result poses important question about what the results of typically developing individuals divided in groups of high and low AQ scorers represents, as for example, some authors have suggested that individuals with low autistic traits do not show sensitivity for capturing differences between emotions (Nixima, Fujimori, & Okanoya, 2013). Furthermore, similarities of pars opercularis region to the M1 indicate their anatomical connection. The beta-band is found to have an origin within M1, but as it has been thought to be anatomically connected with inferior frontal gyrus (IFG, pars opercularis), the core region of the MNS, representing downstream of the IFG, it is considered to contain functional properties of the IFG (Caetano et al., 2007; Dum & Strick, 2005; Hari et al., 1998).

However, beta decreases over STS showed different interaction between conditions, with more important differences between AQ groups than the Relatives and Non-Relatives groups. In this region, the High AQ group did not show any difference between Circle and other conditions, whereas the Low AQ group showed differences between Circle and all main conditions in the left hemisphere, whereas in the right hemisphere, the Low AQ group and the Relatives group showed similar results, with larger beta decreases for Emotion than Scrambled condition. The STS is the only region that shows this differentiation between Scrambled and Emotion conditions. It is possible that the Scrambled condition could be also taken as a baseline, non-biological motion condition. If the Circle condition can be

questioned as being used as a baseline condition because of its requirement for recognising direction of motion, then results found over STS can be considered even more important. It is important to mention that the Relatives group belongs predominantly in the Mid AQ group, with AQ scores positioned in the middle between the Low and High AQ group scores. In sum, results over the STS show the importance of autistic tendency for explaining results, with the High AQ group not showing any significant results.

It is important to mention that results of beta band osciallations can be also interpreted in an alterntive ways, for example, suggesting that their presence represent the tendency of the sensorimotor system to maintain the status quo (Engel & Fries, 2010).

Concerning the STS, correlation analysis showed the importance of SQ scores for explaining beta decreases over STS for Emotion condition for all three groups. High SQ scores indicate a strong drive for systemising, which is analysing and extracting rules that underlie a system (Billington, Baron-Cohen, & Bor, 2008), and even a strong drive to create systems. Systemising has been associated with increased local perceptual bias (Billington, Baron-Cohen, & Bor, 2008). It may not be surprising to find an important role of systemising in processing of biological motion stimuli over STS as the STS is considered not to contain the mirror neurons *per se,* but is considered to represent a critical area of an extended mirroring process (Pineda, 2008). Thompson, Clarke, Stewart and Puce (2005) showed that processing of biological movement in STS relies on a body configuration-based model by using form cues in order to process biological motion. Furthermore, Saxe, Xiao, Kovacs, Perrett and Kanwisher, (2004b) showed that right posterior STS (pSTS) is sensitive to the relationship of body movements and the context of the environment, showing its important role in recognising intentions from actions.

Correlation analysis indicated the importance of age for explaining results, particularly for the Relatives group, which had a larger number of older participants. In the Relatives group, there was a negative correlation between age and Direction decreases over the right hemisphere that was seen over M1 and S1, but showed an opposite correlation (positive correlation) over STS, suggesting that the older age of participants in this group can explain some of results. This is important for this group, as it consistently showed smaller beta decreases for Direction condition when compared to both the Scrambled and Emotion conditions. Research on biological motion that examined the effects of age mostly suggested that age-related effects on biological motion can be due to perceptual differences, as older participants showed a local-processing bias and lower performance on biological motion

decoding, although authors suggested that other factors may be more predictive in explaining the role of age in social perception (Insch, Bull, Phillips, Allen, & Slessor, 2012).

One of the important findings in this study is right hemispheric lateralisation for beta (and alpha) decreases for the biological motion conditions in most of the regions investigated, across all subjects. Several studies have indicated right hemispheric lateralisation for biological motion processing (Grossman et al., 2000; Herrington, Nymberg, & Schultz, 2011; Pelphrey et al., 2003, 2005). However, hemispheric lateralisation in biological motion processing has not been found in some other studies (Saygin, 2007; Saygin et al., 2004), with a recent study even showing left hemispheric sensitivity for biological motion (Gilaie-Dotan, Kanai, Bahrami, Rees, & Saygin, 2013). Gilaie-Dotan et al. (2013) suggested that hemispheric lateralisation in biological motion processing may reflect differences in tasks and also individual anatomical variability, rather than functional lateralisation (Gilaie-Dotan et al., 2011). In the present study hemispheric lateralisation for each group showed some differences with regard to regions. Over M1, this effect was seen in the Low AQ group for Emotion condition, in the High AQ group for Direction condition, but was not seen in the Relatives group. It indicates that over the M1, the Non-Relatives group showed significant hemispheric lateralisation for biological motion conditions.

Previous studies that examined alpha and beta desynchronisation in response to movement tasks showed larger activity of alpha over post-central and beta over pre-central areas (Salmelin et al., 1995). In the present study, alpha decreases were examined only over S1 regions, following previous findings (Salmelin et al., 1995). However, alpha decreases over S1 showed some important differences in comparison to beta decreases, particularly over M1. Alpha decreases also showed differences between the Relatives and the Non-Relatives groups, showing that only Non-Relative show larger decreases for the Circle when compared to all main conditions, including Emotion. However, this effect was found in the left hemisphere, whereas those important differentiations between Circle and Emotion conditions for beta decrease over M1 were mostly found in the right hemisphere. Another difference is that, whereas the effects found in the Non-Relatives group for beta decrease indicated that they are mostly driven by activities within the High AQ group that showed differentiation between Circle and Emotion conditions. However, for alpha decreases in the left hemisphere, it is only the Low AQ group that showed significant differences between Circle and Emotion conditions, but not the High AQ group or the Relatives group. The MEG research attributes differences between Rolandic alpha and beta oscillations to their different

functions, with the 20-Hz oscillation considered to represent motor function, whereas 10-Hz oscillation relates to sensory function (Tamura et al., 2005).

However, data indicates that beta decreases over M1 are not as strong as those found over STS. Weaker alpha and beta decreases over primary sensorimotor cortex probably can be explained by stimuli. Stimuli and tasks in the present study did not include goal-directed actions, whereas previous MEG studies that established alpha and beta desynchronisation over sensorimotor cortex as an index of MNS used goal directed actions with a hand and a tool (e.g., Järveläinen, Schürmann, & Hari, 2004).

Overall, the study shows beta decreases over important regions that are considered to contain MNS. A support for examination of alpha and beta decreases over several brain areas can be found in the functions of mirror mechanism areas as highly dependent on its anatomical location (Rizzolatti & Sinigaglia, 2010). Action observation – action execution function is particularly related to the parieto-frontal brain circuit. However, what needs further investigation is the connectivity in those areas, particularly during observation of biological motion stimuli and its role in the MNS. Also, it is necessary to see what aspects of visual information processing cause results. Beta oscillations are considered to be an index of perceptual integration, particularly over central-parietal regions (Aisani, Martienerie, Yahia-Cherif, Paradis, & Lorenceau, 2014). This is particularly important in autism research, as individuals with autism show local processing bias (Happé & Frith, 2006), and biological motion stimuli requires integration of local information in order to understand the global whole. A recent study showed differences in processing biological motion between individuals with higher and lower autistic traits (van Boxtel & Lu, 2013). In this study, high autistic traits correlated with decreased global local processing.

It is important to note that in the procedure that computes z-score normalisation based on pre-stimulus and post-stimulus activation there are several important methodological features that may influence results. One of them is the length of the pre-stimulus period. From statistical considerations a longer pre-stimulus period is preferable, however, choosing such a longer Baseline would have involved screen changes (between blank and fixation target). Another important dimension that received less attention is whether the pre-stimulus period is before or after participants received trial instructions. This may be particularly important in tasks with several conditions. In the present study, the pre-stimulus period was a fixation cross that appeared after participants received trial instruction. It is possible that cognitive attention on particular task/condition also influenced the cortical activation during this period. In sum, it is necessary to see whether similar results would be obtained with a pre-stimulus

period that did not include any cognitive activity related to specific condition, something that is already examined in some studies (Cornwell et al., 2013).

One of problems of this study may be the small number of participants in each group, particularly the Relatives group. Also, this group consisted of mostly males and some of its participants were older than other participants. As this study only compared the Relatives group with individuals with high and low autistic traits, results suggest the need to further investigate this group with a proper control group of subjects without ASD relatives. The often used groups are control groups consisting of relatives/parents of individuals with other disabilities to control for stressors caused by raising a child with a disability or living with a sibling with a disability (e.g. Di Michele, Mazza, Cerbo, Roncone, & Casacchia, 2007; Szatmari et al., 2008). However, it is possible that any typically developing group would be suitable.

In sum, the present data shows that some differences may be found between individuals with no first-degree relatives and individuals who have first-degree relatives, but also between individuals with high and low autistic traits, regardless of whether they have first-degree relatives or not. This shows the need for further qualification of the BAP and looking into more social-cognitive measures in order to understand it better.

CHAPTER 9 -

CONCLUSIONS AND FUTURE DIRECTIONS

The major aim of this thesis was to examine social and emotional processing in the broader autism phenotype, particularly in typically developing individuals with higher and lower autistic tendencies (in all experiments), and also in first-degree relatives of individuals with autism (the 3rd experiment). This thesis has contributed to an understanding of the social and emotional processing of typically developing individuals with higher and lower autistic traits, and through this, indirectly to autism research. Its particular contribution is in showing the importance for considering the role of visual processing in emotion perception, and also in showing of importance of looking at cortical and subcortical processing of emotion in autism. This chapter draws conclusions from the basic findings of these studies, and provides a short overview of future directions.

9.1. Review of main findings

9.1.1. First experiment

The main finding was a reduced effect of face inversion in the High AQ group with respect to the amplitude of the N170 peak recorded over the left hemisphere. By comparison, significant face inversion effects were found in the Low and Mid AQ groups. This finding can be explained by the weak central coherence (WCC) theory that states that individuals with autism show local processing bias. Happé and Frith (2006) suggested that finding from face studies could not be generalized to other stimulus categories because of the special status that faces possess "in terms of evolutionary significance and developmental expertise" (p. 13). However, it can be argued that face speciality does not need to be in opposition to the general perceptual mechanisms that influence processing of local and global visual information. The current research showed inversion effects on the N170 amplitudes for both face and houses. Recently, face inversion effects in binocular rivalry were studied with a main aim to see if face inversion effects are face-specific or represent a tendency of visual awareness to give a preference to upright objects (Persike, Meinhardt-Injac, & Meinhardt, 2014). An inversion effect was found for both faces and houses, with a larger inversion effect for faces. The authors suggested that although there is a strong tendency for visual awareness to prefer upright objects, faces may have more important role in this. This would indicate that processing of face stimuli is influenced by local bias in processing of visual information as found in individuals with autism. As it has been argued that faces are perceptually similar, they cannot be properly recognized by relying on feature-based processing but rather on configural processing (Behrmann, Thomas, & Humphreys, 2006). Thus, face processing in

autism may arise from their differences in perceptual processing, and although Behrmann et al. (2006) suggested that perceptual atypicalities in autism are present and are independent of social functions, they also emphasise the need for accounting perceptual characteristics of individuals with autism in both face and non-face processing.

Another important finding in the first experiment relates to and enhanced P200 amplitude (central) seen for inverted sad faces and also an enhanced central Late Positive Potential (LPP) for inverted happy faces found only in the High AQ group, but not in other groups. Previous research has shown atypical processing of sad and happy faces in individuals with autism (e.g., Boraston, Blakemore, Chilvers, & Skuse, 2007; Wallace et al., 2011), and this study shows that this may be caused by more pronounced featural processing of stimuli. The importance of featural and configural information in face processing is presently widely disputed, with some suggesting that their importance probably depends on specific emotions (Bombari et al., 2013). Thus, in addition to the face inversion effect, which has received so much attention, testing of composite effects in recognition of facial emotion would also give important insights for understanding the BAP. Each of those paradigms taps into different aspects of configural information (Baudouin & Humphreys, 2006; Calder & Jansen, 2005; Maurer et al., 2002; Mondloch, Le Grand, & Maurer, 2002). Thus, the face inversion effect shows distortion of first-order relations of faces, whereas the composite effect shows greater sensitivity to holistic information in facial emotion perception (Durand et al., 2007; Farah, Wilson, Drain, & Tanaka, 1998; Maurer et al., 2002; Tanaka & Farah, 1993). These two paradigms of face processing give partial answers about the role of specificity of perceptual characteristics in autism for face processing (Behrmann et al., 2006). Behrmann et al. (2006) emphasized the need for explaining perceptual processing in autism as arising from local bias and/or poor global processing, as something that still needs to be explored in greater detail, particularly in relation to processing of social stimuli. It can be suggested that an investigation of face inversion effect and the composite effects, as tasks that taps into different aspects of configural face processing, could maybe resolve some of those questions, particularly if examined within the same subject sample.

9.1.2. Second experiment

Backward masking resulting in subliminal emotion processing in individuals with different level of autistic traits and main results showed enhanced N200 amplitude for subliminally presented happy faces only in the Low AQ group, but not in the High AQ group.

This study shows that possible group differences can be explained by a weak relevance network in the High AQ group. However, this explanation cannot completely exclude effects of perceptual processing in this group, particularly considering research on face processing and spatial frequencies. Local information is biased towards high-spatial frequencies (HSF) whereas global information is biased towards low-spatial frequencies (LSF), however the relations with underlying parvo and magnocellular physiology are not direct and are still not clear. Previous research have suggested that individuals with autism have difficulties in processing faces in LSF (Deruelle et al., 2004, 2008; Boeschoten et al., 2007a; Vlamings et al., 2010), although there are reports of typical processing of LSF faces (Rondan and Deruelle, 2004). Further research is needed to examine this aspect of visual perceptual processing of facial expressions in autism, with better distinguishing of various facial expression presented processed through LSF and HSF. Examining processing of facial expressions through spatial frequencies with individuals with high and low AQ could give additional insights into emotional processing of those groups, and help put results presented within this thesis into better perceptual explanation.

9.1.3. Third experiment

Processing of biological motion using magnetoencephalography, showed the greatest effects in the ASD Relatives group, with larger beta decreases for Scrambled and Emotion conditions over cortical area M1. However, this group did not show significant decreases for the Emotion condition compared to the Circle (baseline) condition. The Emotion condition task examined differentiation of emotional biological motion, both fearful and happy, without looking at any distinction between emotions. It is proposed that the MNS activation over rostral cortical areas would be sensitive to biological motion representing socially-salient stimuli, in accord with the involvement of the MNS region in theory of mind and intention recognition. Collapsing AQ groups to create the Non-Relatives group showed differentiation between the circle and emotion conditions, suggesting that beta decreases over M1 show differences between the Relatives and Non-Relatives groups. However, decreases over STS, a region also included in the MNS and activated in response to biological motion stimuli (Saygin et al., 2004), showed beta decreases differentiating both biological motion conditions (direction and emotion) from both non-biological motion conditions (scrambled and circle) in the Low AQ group and the Relatives group, but not in the High AQ group. As in the present study, the Relatives group occupied the Mid AQ position based on their AQ scores, and it may be possible that activity over STS is related to AQ scores. A previous study (Freitag et

al., 2008) found reduced activation in STS (and also parietal MNS) in response to biological motion stimuli in individuals with ASD. However, within biological motion research relationship between "low-level" recognition of biological stimuli and "high-level" attribution of emotional states (or intentional actions) to biological motion stimuli still remain unclear. There are some suggestions about the mutual interactions of those levels, with some evidence of lower detection threshold of biological motion stimuli representing anger compared to biological motion stimuli representing "happiness" (Chouchourelou, Matsuka, Harber, & Shiffrar, 2006; Ikeda & Watanabe, 2009). A recent behavioural study (Nackaerts et al., 2012) showed reduced ability in ASD participants during recognition of both biological motions and also emotions from point light displays (PLD). However, the authors suggested that there may be some additional deficits in autistic subjects that could give better explanation for their deficits in recognizing emotions from PLDs.

Future direction within biological motion research with the BAP should include goal-directed actions and also enacting of movement to expand research that examines the MNS in this group. Examination of both performing and observing actions with measuring alpha and beta band suppression over sensorimotor regions could directly compare results with recent studies that use this method with MEG to show that oscillatory activity around 20 Hz over the primary motor cortex (M1) is an index of the human MNS (Caetano, Jousmäki, & Hari, 2007; Hari & Salmelin, 1997; Hari, Salmelin, Makela, Salenius, & Helle, 1997; Salmelin & Hair, 1994; Tamura et al., 2005). Furthermore, future studies should also include analysis of gamma band activity in both individuals with autism and their first-degree relatives. Gama-band deficits in autism have been established through variety of experimental tasks and paradigms including face processing (e.g., Gao et al., 2013; Grice et al., 2001; Rojas et al, 2008), and was also found to be atypical in first-degree relatives of individuals with autism (e.g., Buard, Rogers, Hepburn, Kronberg, & Rojas, 2013; McFadden, Hepburn, Winterrowd, Schmidt, & Rojas, 2012). Indeed, a gamma-band deficit in autism disorder has been proposed to represent a biomarker for autism (Uhlhaas et al., 2010).

9.2. Additional questions and future directions

9.2.1. The meaning of AQ groups

Investigation of individuals with various autistic tendencies can have some advantages compared to working with individuals with autism, particularly related to heterogeneity of autism and differing diagnostic criteria used. In research with facial emotional stimuli this

group of participants can exclude differences due to extensive training with face stimuli that individuals with autism can have through various intervention programs (e.g., Herbrecht et al., 2009), and that are rarely mentioned in research studies on face processing.

However, an area that is still significantly missing in socio-emotional research in the BAP, particularly in individual differences with regard to the level of autistic tendency, is a developmental approach. Autism is a neurodevelopmental disorder, and an important number of research studies have indicated atypical brain maturation in young children with autism (Greimel et al., 2013). The importance of developmental trends is also based on findings of developmental trends in various mechanisms of face processing, including emotion recognition, face memory, face direction, etc. (Campbell et al., 2005, 2006; Wade et al., 2005). In development of emotion research, there is evidence for earlier recognition/categorization of happy and sad facial expressions than fearful and disgusted (Boyatzis, Chazan, & Ting, 1993; Camras & Allison, 1985; Gosselin, 1995; see also Gosselin, 2005; Gosselin & Larocque, 2000), with less clear development patterns for angry faces (e.g., Boyatzis et al., 1993; Gosselin, 1995).

Another important issue within the BAP is a precise explanation of what comparisons of high and low autistic trait really show. As the level of autistic tendency in the general population does not represent a disorder or impairment (by definition), it is difficult to say what level of autistic tendency represents typical/average population results and what might be deemed as traits within the clinical range. It is generally accepted that results in subjects with high AQ represent atypicalities that can be seen in autism, but in milder form. However, there is already a substantial number of research, particularly examining visual processing (both perceptually and physiologically) that have shown that the effect size for the difference between individuals with high and low AQ is large (e.g., Sutherland & Crewther, 2010). It can be probably added that results may be improved by using greater numbers of participants and more universal dividing of participants on those with higher and lower AQ (by using cut scores or specific scores).

Putting autism on the spectrum raises questions about meaning of "normality". Recently, there are more authors that speak about autism as "neurodiversity" rather than "neurological deficiency" (e.g., Kapp et al., 2013). This new positioning of autism is in accord with the social model in disability literature that states that a person is "disabled" because society is not able to properly accommodate his difference (Baker, 2011). This also

look at cultural differences in approaches in autism, with some authors showing that in some cultures autism is still does not have name and individuals who show characteristics of autism are not seen as pathological cases (Grinker, 2007). Even the AQ shows some cultural variation, as seen with Dutch (Ketelaars et al., 2008) and Japanese (Kurita, Koyoma, & Osada, 2005) samples that indicated lower AQ scores among ASD individuals compared to British sample that was originally used in research with the AQ (Baron-Cohen et al., 2001b). Brownlow (2010) reported a discourse analysis study reporting an online discussion of people with autism (including both those with Asperger syndrome and those with autism) in which they challenge the traditional dualism between neurotypicals and people with autism, indicating that autistic traits are superior to neurotypicals, and social hierarchies based on comparison with each other are considered "primitive" (p. 7). They also consider that communication styles of neurotypicals are illogical and impaired. These discussions between people with autism re-position autistic and neurotypical way of behaviour and their experience of the world that they consider to be the only correct one, and Brownlow (2010) considers many of their thoughts showing strong reflection and sophistication that questions lack of theory of mind in autism. This brief overview of idea of neurodiversity shows that examination of autistic traits in general population probably can have significant contribution in this discussion and understanding.

9.2.2. Connectivity

Connectivity analysis can give important insight into socio-emotional difficulties in autism, and it is necessary to have more investigation into connectivity in the BAP. Several line of research suggests importance in connectivity related to both facial emotion processing and the MNS. For example, the amygdala activity is modulated by reciprocal connections from anterior cingulate/medial prefrontal regions and this connection was found to be important for fear processing (Davis & Whalen, 2001). On the other side, it is suggested that reduced connectivity between the frontal and parietal lobes, forming the parieto-frontal MNS, may be neuro-anatomical marker of autism (Perkins et al., 2010). The STS, that in the experiment within this work showed strong beta decreases for BM stimuli and differentiate groups (the High AQ group vs the Low AQ and the ASD Relatives group), has an important role in social-emotional cognition, particularly through its connection with other areas. For example, it is thought that rapid feed forward/feed-back interaction between STS and fronto-limbic pathways has a mediatory role in various important socio-emotional cognitive processes, including perceptual and attentional processes (Haxby et al., 2000; Dolan, 2002;

Jabbi et al., 2014; Pessoa & Adolphs, 2010). Examining connectivity can be particularly important in face research, as recent research indicates a more distributed and interwoven representation of facial emotional expressions (e.g., Jabbi et al., 2014), particularly involving the STS circuitry. This suggests that the BAP research on the role of neural connectivity research would significantly contribute in understanding socio-emotional processing in both autism and the BAP. Autism is characterized by alteration of long-range connectivity in (Courchesne and Pierce, 2005), suggesting underconnectivity (Just et al., 2004), although there are also reports of overconnectivity (Buard et al., 2013; Dominguez et al., 2013).

9.3. Final conclusions

The main aim of research within this dissertation was to apply several experiments that could provide an answer on two important explanations for social-emotion difficulties in autism involving interaction of perceptual characteristics of individuals and social/motivational causes of processing of social-emotional stimuli. Studies were not with people with clinical autism but examined the broad autism phenotype. The first experiment that used the face inversion effect supported weaker face inversion at the face ERP component, the N170, in subjects with the High AQ. Some differences that were found enhanced N200 amplitude for inverted sad faces in this group may also suggest that this effect is influenced by stronger attention to details in this group, although this needs better experimental paradigm to get conclusive results. However, the second experiment with subliminally presented faces that showed absent differentiation of subliminally happy faces in the High AQ group is suggestive of atypicalities of the relevance detector network in this group, that would be more in accord with the second important explanations for social-emotional difficulties in autism, the social orienting model of autism. The last experiment that used biological motion stimuli also points to group differences in relation to beta decrease for point-light displays representing emotions, suggesting that the High AQ group, and also first-degree relatives of people with autism show difficulties with emotion processing. Point-light displays are stimuli that also require integrating light dots that form the stimuli into a global whole to perceive it properly. However, research with recognition of biological motion in autism is not conclusive, with some research studies suggesting that there is normal processing of simple actions, but difficulty with processing of more complex social stimuli, such as emotions (Moore et al., 1997; Hubert et al., 2007; Parron et al., 2008). Overall, different experimental paradigms and different task give different insights about autism research, but based on results of, particularly both face experiments in this thesis, it can be

concluded that for explaining social-emotional difficulties in autism, probably both models of autism, perceptual and social orienting explanations, have importance. Already several researchers confirmed the importance of both of those explanations. Kaiser and Shiffrar (2009) stated that visual perception is important for explaining both social and cognitive difficulties in autism. Behrmann et al. (2006) reviewed research on face processing in autism and concluded that face processing difficulties in autism may arise from both perceptual characteristics of this group characterized by local bias and also by social and/or motivational sources. This is the main conclusion that can also be drawn from experimental studies in the present work, although it is also important to emphasize that result depends on experimental paradigms.

9.4. Summary

This research contributes to several important areas within social and emotional research that potentially can give insight into the broad autism phenotype. Firstly, it examined both cortical and subcortical mechanisms as both of them may be important for explaining emotion processing deficits in autism. Research on subcortical mechanisms in emotion processing in autism can give important insight into social and emotional functioning of this disorder because subcortical structures have a strong influence on emotion processing, facial memory and eye gaze that subsequently have a strong effect on how humans gain and maintain socially appropriate behaviour (Amaral, 2002; Calder, Lawrence, & Young, 2001; Skuse, 2006). In recent years there has been a strong increase in interest in the BAP, not only examining the first-degree relatives of individuals of autism, but also in the typically developing individuals with different level of autistic tendencies. This thesis has advanced to some degree understanding of socio-emotional processing in the BAP, and highlights some areas that require further research before autism is understood.

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11. Appendices

APPENDIX 1.

Ethics Declaration: Email correspondence about ethics clearance

Experiment 1

Dear Prof Crewther,

SUHREC Project 2010/161 An investigation into the interaction of emotion and cognition

Prof David Crewther, FLSS/Ms Svjetlana Vukusic

Approved Duration: 11/08/2011 To 28/02/2013 [Adjusted]

I refer to the ethical review of the above project protocol undertaken on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by SUHREC Subcommittee (SHESC1) at a meeting held on 30 July 2010. Your responses to the review as e-mailed on

15, 25 (3 e-mails), 26 July and 3 August 2011 (3 e-mails) were reviewed by SHESC1 delegates.

 I am pleased to advise that, as submitted to date, the project has approval to proceed in line with standard on-going ethics clearance conditions here outlined.

 - All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.

 - The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

 - The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/ clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

 - At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

 - A duly authorised external or internal audit of the project may be undertaken at any time.

 Please contact me if you have any queries about on-going ethics clearance. The SUHREC project number should be quoted in communication. Chief Investigators/Supervisors and Student Researchers should retain a copy of this e-mail as part of project record-keeping.

Best wishes for the project.

Yours sincerely

Kaye Goldenberg

Secretary, SHESC1

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Kaye Goldenberg

Administrative Officer (Research Ethics)

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Experiment 2:

To: Prof David Crewther, FLSS/Ms Svjetlana Vukusic

 Dear Prof Crewther,

SUHREC Project 2010/161 Electrophysiological correlates of conscious and unconscious processing of emotional faces in individuals with high and low autistic traits

Prof David Crewther, FLSS/Ms Svjetlana Vukusic

Approved Duration: 11/08/2011 To 28/02/2013 [Adjusted]

I refer to the ethical review of the above project protocol undertaken on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by SUHREC Subcommittee (SHESC1) at a meeting held on 30 July 2010. Your responses to the review as e-mailed on

15, 25 (3 e-mails), 26 July and 3 August 2011 (3 e-mails) were reviewed by SHESC1 delegates.

 I am pleased to advise that, as submitted to date, the project has approval to proceed in line with standard on-going ethics clearance conditions here outlined.

 - All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

 - The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/ clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

 - At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

 - A duly authorised external or internal audit of the project may be undertaken at any time.

 Please contact me if you have any queries about on-going ethics clearance. The SUHREC project number should be quoted in communication. Chief Investigators/Supervisors and Student Researchers should retain a copy of this e-mail as part of project record-keeping.

 Best wishes for the project.

 Yours sincerely

 Kaye Goldenberg

Secretary, SHESC1

****

Kaye Goldenberg

Administrative Officer (Research Ethics)

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Experiment 3:

To: Prof David Crewther/Ms Svjetlana Vukusic; FLSS

 Dear David and Svjetlana

SUHREC Project 2012/110 Biological motion processing in first-degree relatives of individuals with autism: A combined magnetoencephalographic (MEG) and eye movement study

Prof David Crewther, Ms Svjetlana Vukusic, Dr Jordy Kaufman, Dr Joseph Corciari; FLSS

Approved Duration: 26/10/2012 To 01/11/2013 [Adjusted]

I refer to the ethical review of the above project protocol undertaken by Swinburne's Human Research Ethics Committee (SUHREC). As part of the review, a revised protocol was submitted (emailed 27 September 2012 superseding two previous emails) for expedited review by SUHREC delegate(s). Your responses to the feedback from the delegate(s), as emailed on 26 October 2012, appear in line with the approval conditions for the project.

 I am pleased to advise that, as submitted to date, the project may proceed in line with standard on-going ethics clearance conditions here outlined.

 - All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.

 - The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

 - The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/ clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

 - At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project.

 - A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the SUHREC project number. Copies of clearance emails should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely

Sheila

for Keith Wilkins

Secretary, SUHREC

****

Sheila Hamilton-Brown

Administrative Officer (Research Ethics & Biosafety)

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APPENDIX 2. – Consent Information Statement, Consent Form and Personal information sheet for each experiment

Experiment 1

Consent Information Statement

Project Title: Global-local processing and its relationship to face and facial expression processing in autistic traits: An event-related potentials (ERP) study

Investigators: Ms Svjetlana Vukusic (PhD student), Professor David Crewther (Principal Coordinating Supervisor), Dr Jordy Kaufman, Senior Research Fellow (Coordinating supervisor), Dr Joseph Ciorciari, Senior Lecturer (Associate Supervisor) , Dr Pat Johnston, Lecturer (External Associate Supervisor).

Introduction to Project and Invitation to Participate

You are invited to participate in a study that will help us learn more about how emotions are processed in the brain, and how attention and face configuration contribute to emotion processing.

About the Project

The aim of the present study is to investigate the relationship between face processing and global/local processing in subjects with high and low autistic traits.

The study will examine brain electrical activity and behavioural outcomes that are involved in processing facial identity and facial emotional expressions. Also, through presenting faces in upward and upside-down orientation we will examine how holistic (global) presentation of faces, usually considered to be present in upright faces, and distortion of holistic (global) presentation of faces, considered to be present in inverted faces, influence processing of facial identity and facial emotional expressions and what are neural correlates of this.

We will also examine how individuals with different thinking styles process facial identity and facial emotional expressions. To examine this, we will divide participants into two groups, based on their high and low autistic traits as measured by the Autistic Quotient (AQ) questionnaire.

In the second part of the experiment we will examine whether the participants with high and low autistic traits differ on the task that measures global and local perceptual processing not related to faces. Global and local perceptual processing will be measured by the Navon Figure task (large letters built of small letters).

Finally, we will try to find out if there is any correlation between global and local perceptual processing and processing of facial identity and facial emotional expressions.

This study may provide some important additional insights into neural encoding of faces and facial emotional expressions, global and local perceptual processing, and could show us whether there is any correlation between face processing and (non-face) global-local perceptual processing as examined by the Navon task. These findings may be particularly important for explaining socio-cognitive impairments in individuals with autism.

Project and Research Interests

This study is partly to satisfy the requirements for a PhD thesis that investigates the interaction between emotion and cognition.

What does Participation Involve?

Participation in this study is voluntary and involves completing questionnaires and measuring your brain electrical activity with an electroencephalogram (*EEG*), while you make response to various pictures of human faces and the Navon figures (large letters built of small letters) that will be presented at the computer screen. Questionnaires will take about 45 minutes and measuring brain electrical activity will take about 1 hour to complete.

We will measure you brain activity with an EEG "sensor net" that is fitted on your head. This technique has been used at numerous clinics and research institutions for many years and no deleterious side effects have been reported. You can remove the electrodes at any time.

Who can participate in the study?

You can participate in the study if you are at least 18 years old.

If you have a neurological disorder or brain injury please do not take part in the study

Participant Rights and Interests

Because we use electrical equipment (computers, EEG, etc.), there is always a minor risk of electrical shock. However, all of our equipment is tested to conform to Australian and/or International safety standards.

Your participation is completely voluntary. You can withdraw from the study at any time and for any reason. The study will only proceed once you have read and signed the **consent** form.

All consent forms, questionnaires, data and recordings will be kept confidential and stored securely (in either a locked cabinet or digitally on a password secured computer).

Research Output

Results of this study will be used for completion of PhD thesis, and they also may be submitted for publication in an academic journal. Only group results would be used for

publishing and no individual's responses or individual's names would be identifiable. If you wish to receive the completed study a copy will be made available for you upon your request.

Queries – who to contact

Any questions regarding this project can be directed to:

Professor David Crewther
Brain Sciences Institute
400 Burwood Road
Hawthorn, VIC 3122
(03)92145877
dcrewther@swin.edu.au

CONSENT FORM

Project Title: Global-local processing and its relationship to face and facial expression processing in autistic traits: An event-related potentials (ERP) study

Investigators: Ms Svjetlana Vukusic (PhD student), Professor David Crewther (Principal Coordinating Supervisor), Dr Jordy Kaufman, Senior Research Fellow (Coordinating supervisor), Dr Joseph Ciorciari, Senior Lecturer (Associate Supervisor), Dr Pat Johnston, Lecturer (External Associate Supervisor).

1. I consent to participate in the project named above. I have been provided a copy of the project information statement and this consent form and any questions I have asked have been answered to my satisfaction.

Name:………………………………………………………………….

2. I acknowledge that:

(a) The possible side effects have been explained to me to my satisfaction;

(b) I can withdraw from the study at any time, without explanation;

(c) The project is for the purpose of research and not for profit;

(d) any personal or health information gathered in the course of and as the result of me participating in this project will be (i) collected and retained for the purpose of this project and (ii) accessed and analysed by the researcher(s) for the purpose of conducting this project;

(e) I have not had any neurological disorder or brain injury"
(f) My anonymity is preserved and I will not be identified in publications or otherwise without my express written consent;

(g) I understand that this study does not constitute a diagnostic test in any way. The data will be used solely to test and generate scientific hypotheses. It will not be used to diagnose, test or judge a particular participant.

By signing this document I agree to participate in this project.

- I additionally *would like to receive a summary of the findings*   YES / NO
- *I agree to take part in a laboratory experiment and have EEG recordings made YES/NO*

Name:…………………………………………………………………………

Postal Address: …………………………………………………………………

Signature…………………………………… Date…….…………………………

Email:……………………………………………………………………………

Personal Information Sheet

Full name:_____

Subject #:_____

NOTE: *1.Personal details will remain confidential*

        *2. Please **CIRCLE** your response.*

Today's Date_____

Age_____

Gender: a) female

          b) male

Handedness: a) right handed

            b) left handed

Have you been a subject for any type of study at BSI before? **Y / N**

Occupation_____

Years of education _____

What is the highest level of education you have completed?

a) Completed primary school
b) Completed secondary school?
c) Completed TAFE
d) Completing TAFE

e) Completed undergraduate degree
f) Completing undergraduate degree
g) Completed postgraduate degree
h) Completing postgraduate degree

Thank you for taking the time to complete this questionnaire

Consent Information Statement

Project Title: Electrophysiological correlates of conscious and unconscious processing of emotional faces in individuals with high and low autistic traits

Investigators: Ms Svjetlana Vukusic (PhD student), Professor David Crewther (Principal Coordinating Supervisor), Dr Jordy Kaufman, Senior Research Fellow (Coordinating supervisor), Dr Joseph Ciorciari, Senior Lecturer (Associate Supervisor), Dr Patrick Johnston, Lecturer (External Associate Supervisor).

Introduction to Project and Invitation to Participate

You are invited to participate in a study that will help us learn more about how emotions are processed in the brain and more specifically how individual differences in the level of autistic tendencies influences unconscious processing of emotions.

About the Project

The aim of this study is to examine unconscious (below awareness) and conscious processing of various facial emotions by measuring brain activity. We will look whether there are differences in unconscious and conscious emotions processing and also whether there are individual differences among participants based on their responses to the Autism Quotient (AQ) questionnaire.

This study may provide some important additional insights into neural encoding of emotional faces. More specifically, it may provide some new insights into individual differences in autistic tendencies in processing emotional stimuli bellow level of conscious perception. These findings may be particularly important for explaining socio-cognitive impairments in individuals with autism.

Project and Research Interests

This study is partly to satisfy the requirements for a PhD thesis that investigates social-emotional processing in autism phenotype.

What does Participation Involve?

Participation in this study is voluntary and involves completing questionnaires and measuring your brain electrical activity with an electroencephalogram (*EEG*), while you make response to various pictures of human faces that will be presented at the computer screen. Questionnaires will take about 45 minutes and measuring brain electrical activity will take about 1 hour to complete.

We will measure your brain activity with an EEG "sensor net" that is fitted on your head. This technique has been used at numerous clinics and research institutions for many years and no deleterious side effects have been reported. You can remove the electrodes at any time.

Who can participate in the study?

You can participate in the study if you are at least 18 years old.

If you have a neurological disorder or brain injury please do not take part in the study

Participant Rights and Interests

Because we use electrical equipment (computers, EEG, etc.), there is always a minor risk of electrical shock. However, all of our equipment is tested to conform to Australian and/or International safety standards.

Your participation is completely voluntary. You can withdraw from the study at any time and for any reason. The study will only proceed once you have read and signed the **consent** form.

All consent forms, questionnaires, data and recordings will be kept confidential and stored securely (in either a locked cabinet or digitally on a password secured computer).

It is not expected that any part of this study will cause any problem. However if participation raises any issues which you would like to discuss with a counsellor, please contact a crisis helpline or support service in your local area.

In Australia you can contact:
The Swinburne Psychology Clinic: (03) 9214 8653
(The Swinburne Psychology Clinic provides low-cost psychological services.)

 Lifeline: 13 11 14

Research Output

Results of this study will be used for completion of PhD thesis, and they also may be submitted for publication in an academic journal or as poster presentation. Only group results would be used for publishing and no individual's responses or individual's names would be identifiable. If you wish to receive the completed study a copy will be made available for you upon your request.

Queries – who to contact

Any questions regarding this project can be directed to:

Professor David Crewther
ATC 929
427-451 Burwood Road

Hawthorn, VIC 3122
(04)92145877
dcrewther@swin.edu.au

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.
Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

CONSENT FORM

Project Title: Electrophysiological correlates of conscious and unconscious processing of emotional faces in individuals with high and low autistic traits

Investigators: Ms Svjetlana Vukusic (PhD student), Professor David Crewther (Principal Coordinating Supervisor), Dr Jordy Kaufman, Senior Research Fellow (Coordinating supervisor), Dr Joseph Ciorciari, Senior Lecturer (Associate Supervisor), Dr Patrick Johnston, Lecturer (External Associate Supervisor).

1. I consent to participate in the project named above. I have been provided a copy of the project information statement and this consent form and any questions I have asked have been answered to my satisfaction.

Name:……………………………………………………………….

2. I acknowledge that:

(a) The possible side effects have been explained to me to my satisfaction;

(b) I can withdraw from the study at any time, without explanation;

(c) The project is for the purpose of research and not for profit;

(d) any personal or health information gathered in the course of and as the result of me participating in this project will be (i) collected and retained for the purpose of this project and (ii) accessed and analysed by the researcher(s) for the purpose of conducting this project;

(e) I have not had any neurological disorder or brain injury"
(f) My anonymity is preserved and I will not be identified in publications or otherwise without my express written consent;

(g) I understand that this study does not constitute a diagnostic test in any way. The data will be used solely to test and generate scientific hypotheses. It will not be used to diagnose, test or judge a particular participant.

By signing this document I agree to participate in this project.

- I additionally *would like to receive a summary of the findings* **YES / NO**
- *I agree to take part in a laboratory experiment and have EEG recordings made* ***YES/NO***

Name:……………………………………………………………………

Postal Address: ……………………………………………………………….

Signature…………………………………… Date.......…………………………

Email:…………………………………………………………………………

Personal Information Sheet

Subject #:_____

Full name:_____

NOTE: *1. Personal details will remain confidential*

      *2. P*lease **CIRCLE** *your response.*

Today's Date_____

Year of birth_____

Gender: a) female

        b) male

Handedness: a) right handed

          b) left handed

Occupation_____

Years of education _____

What is the highest level of education you have completed?

    i)   Completed primary school
    j)   Completed secondary school?
    k)   Completed TAFE
    l)   Completing TAFE
    m)   Completed undergraduate degree
    n)   Completing undergraduate degree

o) Completed postgraduate degree
p) Completing postgraduate degree

Thank you for taking the time to complete this questionnaire

Participant Consent Information Statement

Project Title: Biological motion processing in first-degree relatives of individuals with autism: A combined magnetoencephalographic (MEG) and eye movement study

Investigators: Ms Svjetlana Vukusic (PhD student), Professor David Crewther (Principal Coordinating Supervisor), Dr Jordy Kaufman, Senior Research Fellow (Coordinating supervisor), Dr Joseph Ciorciari, Senior Lecturer (Associate Supervisor).

About the Study

This study is a part of a PhD project on social and emotional processing in autism phenotype.

The aim of this study is to examine brain activity and eye movements during viewing of biological motion. We will look whether there are differences in biological motion processing among participants based on their responses to the Autism Quotient (AQ) questionnaire, and also between first degree relatives (parents/adult siblings) of individuals with autism and controls with no first degree relatives with autism.

Biological motion refers to the representation of human actions using point-light displays. Point–light displays are generated by attaching dots onto key joints of a moving actor and then filming the results. In this study you will need to perform various tasks by looking at point-light displays showing different emotions, gender and directions of movement.

Who can participate in the study?

You can participate in the study if you are at least 18 years old.

If you a neurological disorder or brain injury please do not take part in the study.

What does Participation Involve?

Participation in this study is voluntary and involves completing questionnaires through an online web site or in the laboratory, and then measuring brain electrical activity with a magnetoencephalograph (MEG) together with eye movements with an eye tracker, while you make responses to various movies of point-light walkers that will be presented on a computer screen.

The magnetoencephalograph (MEG) is a safe, non-invasive technique used to measure electromagnetic activity of the brain. It does not emit radiation or magnetic fields.

The MEG is housed inside a shielded room designed to reduce interference. The researchers will be on the outside of this specially designed room but you will be able to speak to the researchers via an intercom at all times.

Prior to entering the room you will be asked to remove any metal from your clothes, or to get changed into non-metallic clothes provided by the researchers. Although MEG presents no dangers to anyone metal on clothes and on your person can destroy the sensors of the MEG, so no metallic objects can be taken into the special MEG room.

Please read the accompanying document MEG Pre-Scan Information (MEG13) for details of the scanning process and for requirement of wearing as little metallic/magnetic materials as possible. The MEG is an extremely sensitive instrument that can measure magnetic fields less than one-billionth of the earth's magnetic field. Hence we have to protect the instrument from strong fields produced by metals or by mobile phones.

You will sit with your head inside a 'helmet' of special sensors that detect the tiny magnetic signals produced by the brain. This technique has been used at numerous clinics and research institutions and no deleterious side effects have been reported. It is completely safe. You can leave the scanner at any time.

Examples of MEG scanner

We will also measure movement of your eyes with attached eye tracking device. The eye tracker consists of a high-speed camera connected to a dedicated host computer. Once focussed, the system locks onto your pupil image and then measures where your eyes are pointing while performing tasks.

Questionnaires will take about 30 minutes and can be complete through an online web site, and measuring brain electrical activity together with eye movements will take about 90 minutes to complete.

Online Survey

You are invited to complete following questionnaires: the Autism Spectrum Quotient (AQ), the Empathy Quotient (EQ), the Revised Cambridge Personality Questionnaire and a personal information sheet. Completion of questionnaires will take approximately 30 minutes.

After completing questionnaires, you will be invited to participate in a further study that involves scanning of the brain and completing a behavioural measure of general intelligence. These tasks will be conducted in the Advanced Technologies Centre (ATC), Hawthorn. Your completion of the questionnaires will be taken as your consent to participate in this component of the study. You are free to decide whether or not you wish to participate in the further study in the ATC after completing the online questionnaires. You are free to withdraw consent and discontinue participation at any time.

If you are interested in participating in the further study in the ATC, please provide your details (where requested) in the online questionnaire. The data from your online questionnaire will be matched with the data you provide during testing in the ATC. Once the data matching process has been completed, your name will be removed from the data, therefore the data you provide will be anonymous.

Participant Rights and Interests

The MEG is completely safe and cannot possibly cause any harm, but because we use electrical equipment (computers, MEG, etc.), there is always a minor risk of electrical shock. However, all of our equipment is tested to conform to Australian and/or International safety standards.

Your participation is completely voluntary. You can withdraw from the study at any time and for any reason. The study will only proceed once you have read and signed the **consent** form. You will be reimbursed for your participation in MEG study.

All consent forms, questionnaires, data and recordings will be kept confidential and stored securely (in either a locked cabinet or digitally on a password secured computer).

It is not expected that any part of this study will cause any problem. However if participation raises any issues which you would like to discuss with a counsellor, please contact a crisis helpline or support service in your local area.

In Australia you can contact:
The Swinburne Psychology Clinic (provides low-cost psychological services): (03) 9214 8653
Lifeline: 13 11 14

Research Output

Results of this study will be used for completion of PhD thesis, and they also may be submitted for publication in an academic journal or as poster presentation. No individual's name would be identifiable. Only group results would be used for publishing and no individual's responses or individual's names would be identifiable. If you wish to receive the completed study a copy will be made available for you upon your request.

Queries – who to contact

Any questions regarding this project can be directed to:

Professor David Crewther
ATC 929
427-451 Burwood Road
Hawthorn, VIC 3122
92145877
dcrewther@swin.edu.au

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.
Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

CONSENT FORM

Project Title: Biological motion processing in first-degree relatives of individuals with autism: A combined magnetoencephalographic (MEG) and eye movement study

Investigators: Ms Svjetlana Vukusic (PhD student), Professor David Crewther (Principal Coordinating Supervisor), Dr Jordy Kaufman, Senior Research Fellow (Coordinating supervisor), Dr Joseph Ciorciari, Senior Lecturer (Associate Supervisor).

1. I consent to participate in the project named above. I have been provided a copy of the project information statement and this consent form and any questions I have asked have been answered to my satisfaction.

2. I acknowledge that:

   (a) The possible side effects have been explained to me to my satisfaction;

   (b) I can withdraw from the study at any time, without explanation;

   (c) The project is for the purpose of research and not for profit;

(d) any personal or health information gathered in the course of and as the result of me participating in this project will be (i) collected and retained for the purpose of this project and (ii) accessed and analysed by the researcher(s) for the purpose of conducting this project;

(e) I have not had any neurological disorder or brain injury"
(f) My anonymity is preserved and I will not be identified in publications or otherwise without my written consent;

(g) I understand that this study does not constitute a diagnostic test in any way. The data will be used solely to test and generate scientific hypotheses. It will not be used to diagnose, test or judge a particular participant

(h) I understand that I will receive $50 after the completion of MEG to compensate for time.

By signing this document I agree to participate in this project.

I agree to complete MEG Pre-Scan Information (MEG-13)   **YES / NO**
I agree to take part in a laboratory experiment and have MEG recordings and eye movement examination made   **YES / NO**
I additionally *would like to receive a summary of the findings*   **YES / NO**

Name:…………………………………………………………………………

Email:………………………………………………………………………

Date.......………………………………………………………………………

Signature:…………………………………………………………………………

Personal Information Sheet

NOTE: *1.Personal details will remain confidential*

Year of birth_____

Gender: a) Female

       b) Male

Handedness: a) Right handed

b) Left handed

Occupation_____

Years of education _____

What is the highest level of education you have completed?

Completed primary school
Completed secondary school?
Completed TAFE
Completing TAFE
Completed undergraduate degree
Completing undergraduate degree
Completed postgraduate degree
Completing postgraduate degree

Do you have a fist–degree relative (children, siblings) diagnosed with autism?

No

Yes

If you answered "Yes", please give us some information about your first-degree relative(s) with autism:

How many first-degree relatives (with a formal diagnosis of autism) diagnosed with autism do you have?:

_____

What is official diagnosis?

Autism

Asperger Syndrome

Pervasive developmental disorder not otherwise classified

What is his/her age?:_____

What is his/her gender? a) Female   b) Male

(At the end of online survey)

If you would like to participate in further testing, please give us your contact details:

Full name:

Email address:

APPENDIX 3: <u>The Autism Spectrum Quotient (AQ)</u>

<u>How to fill out the questionnaire</u>

Below are a list of statements. Please read each statement <u>very carefully</u> and rate how strongly you agree or disagree with it by circling your answer.

1.	I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2.	I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3.	If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4.	I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5.	I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6.	I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7.	Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8.	When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9.	I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10.	In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11.	I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12.	I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13.	I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14.	I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15.	I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16.	I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17.	I enjoy social chit-chat.	definitely	slightly	slightly	definitely

		agree	agree	disagree	disagree
18.	When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19.	I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
20.	When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21.	I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22.	I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23.	I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24.	I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25.	It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26.	I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27.	I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28.	I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29.	I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30.	I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31.	I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32.	I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33.	When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34.	I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35.	I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree

36.	I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37.	If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38.	I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
39.	People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree
40.	When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree
41.	I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42.	I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43.	I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44.	I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45.	I find it difficult to work out people's intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46.	New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree
47.	I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48.	I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49.	I am not very good at remembering people's date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50.	I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree

APPENDIX 4. THE EMPATHY QUOTIENT (EQ)

How to fill out the questionnaire

Below are a list of statements. Please read each statement <u>very carefully</u> and rate how strongly you agree or disagree with it by circling your answer. There are no right or wrong answers, or trick questions.

1.	I can easily tell if someone else wants to enter a conversation.	strongly agree	slightly agree	slightly disagree	strongly disagree
2.	I find it difficult to explain to others things that I understand easily, when they don't understand it first time.	strongly agree	slightly agree	slightly disagree	strongly disagree
3.	I really enjoy caring for other people.	strongly agree	slightly agree	slightly disagree	strongly disagree
4.	I find it hard to know what to do in a social situation.	strongly agree	slightly agree	slightly disagree	strongly disagree
5.	People often tell me that I went too far in driving my point home in a discussion.	strongly agree	slightly agree	slightly disagree	strongly disagree
6.	It doesn't bother me too much if I am late meeting a friend.	strongly agree	slightly agree	slightly disagree	strongly disagree
7.	Friendships and relationships are just too difficult, so I tend not to bother with them.	strongly agree	slightly agree	slightly disagree	strongly disagree
8.	I often find it difficult to judge if something is rude or polite.	strongly agree	slightly agree	slightly disagree	strongly disagree
9.	In a conversation, I tend to focus on my own thoughts rather than on what my listener might be thinking.	strongly agree	slightly agree	slightly disagree	strongly disagree
10.	When I was a child, I enjoyed cutting up worms to see what would happen.	strongly agree	slightly agree	slightly disagree	strongly disagree
11.	I can pick up quickly if someone says one thing but means another.	strongly agree	slightly agree	slightly disagree	strongly disagree
12.	It is hard for me to see why some things upset people so much.	strongly agree	slightly agree	slightly disagree	strongly disagree

13.	I find it easy to put myself in somebody else's shoes.	strongly agree	slightly agree	slightly disagree	strongly disagree
14.	I am good at predicting how someone will feel.	strongly agree	slightly agree	slightly disagree	strongly disagree
15.	I am quick to spot when someone in a group is feeling awkward or uncomfortable.	strongly agree	slightly agree	slightly disagree	strongly disagree
16.	If I say something that someone else is offended by, I think that that's their problem, not mine.	strongly agree	slightly agree	slightly disagree	strongly disagree
17.	If anyone asked me if I liked their haircut, I would reply truthfully, even if I didn't like it.	strongly agree	slightly agree	slightly disagree	strongly disagree
18.	I can't always see why someone should have felt offended by a remark.	strongly agree	slightly agree	slightly disagree	strongly disagree
19.	Seeing people cry doesn't really upset me.	strongly agree	slightly agree	slightly disagree	strongly disagree
20.	I am very blunt, which some people take to be rudeness, even though this is unintentional.	strongly agree	slightly agree	slightly disagree	strongly disagree
21.	I don't tend to find social situations confusing.	strongly agree	slightly agree	slightly disagree	strongly disagree
22.	Other people tell me I am good at understanding how they are feeling and what they are thinking.	strongly agree	slightly agree	slightly disagree	strongly disagree
23.	When I talk to people, I tend to talk about their experiences rather than my own.	strongly agree	slightly agree	slightly disagree	strongly disagree
24.	It upsets me to see an animal in pain.	strongly agree	slightly agree	slightly disagree	strongly disagree
25.	I am able to make decisions without being influenced by people's feelings.	strongly agree	slightly agree	slightly disagree	strongly disagree
26.	I can easily tell if someone else is interested or bored with what I am saying.	strongly agree	slightly agree	slightly disagree	strongly disagree
27.	I get upset if I see people suffering on news programmes.	strongly agree	slightly agree	slightly disagree	strongly disagree

28.	Friends usually talk to me about their problems as they say that I am very understanding.	strongly agree	slightly agree	slightly disagree	strongly disagree
29.	I can sense if I am intruding, even if the other person doesn't tell me.	strongly agree	slightly agree	slightly disagree	strongly disagree
30.	People sometimes tell me that I have gone too far with teasing.	strongly agree	slightly agree	slightly disagree	strongly disagree
31.	Other people often say that I am insensitive, though I don't always see why.	strongly agree	slightly agree	slightly disagree	strongly disagree
32.	If I see a stranger in a group, I think that it is up to them to make an effort to join in.	strongly agree	slightly agree	slightly disagree	strongly disagree
33.	I usually stay emotionally detached when watching a film.	strongly agree	slightly agree	slightly disagree	strongly disagree
34.	I can tune into how someone else feels rapidly and intuitively.	strongly agree	slightly agree	slightly disagree	strongly disagree
35.	I can easily work out what another person might want to talk about.	strongly agree	slightly agree	slightly disagree	strongly disagree
36.	I can tell if someone is masking their true emotion.	strongly agree	slightly agree	slightly disagree	strongly disagree
37.	I don't consciously work out the rules of social situations.	strongly agree	slightly agree	slightly disagree	strongly disagree
38.	I am good at predicting what someone will do.	strongly agree	slightly agree	slightly disagree	strongly disagree
39.	I tend to get emotionally involved with a friend's problems.	strongly agree	slightly agree	slightly disagree	strongly disagree
40.	I can usually appreciate the other person's viewpoint, even if I don't agree with it.	strongly agree	slightly agree	slightly disagree	strongly disagree

APPENDIX 5. The Systemizing Quotient (SQ)

How to fill out the questionnaire

Below is a list of statements. Please read each statement <u>very carefully</u> and rate how strongly you agree or disagree with it by typing an 'X' in the appropriate box. There are no right or wrong answers, or trick questions.

1.	I find it very easy to use train timetables, even if this involves several connections.	strongly agree	slightly agree	slightly disagree	strongly disagree
2.	I like music or book shops because they are clearly organised.	strongly agree	slightly agree	slightly disagree	strongly disagree
3.	I would not enjoy organising events e.g. fundraising evenings, fetes, conferences.	strongly agree	slightly agree	slightly disagree	strongly disagree
4.	When I read something, I always notice whether it is grammatically correct.	strongly agree	slightly agree	slightly disagree	strongly disagree
5.	I find myself categorising people into types (in my own mind).	strongly agree	slightly agree	slightly disagree	strongly disagree
6.	I find it difficult to read and understand maps.	strongly agree	slightly agree	slightly disagree	strongly disagree
7.	When I look at a mountain, I think about how precisely it was formed.	strongly agree	slightly agree	slightly disagree	strongly disagree
8.	I am not interested in the details of exchange rates, interest rates, stocks and shares.	strongly agree	slightly agree	slightly disagree	strongly disagree
9.	If I were buying a car, I would want to obtain specific information about its engine capacity.	strongly agree	slightly agree	slightly disagree	strongly disagree
10.	I find it difficult to learn how to programme video recorders.	strongly agree	slightly agree	slightly disagree	strongly disagree
11.	When I like something I like to collect a lot of different examples of that type of object, so I can see how they differ from each other.	strongly agree	slightly agree	slightly disagree	strongly disagree
12.	When I learn a language, I become intrigued by its grammatical rules.	strongly agree	slightly agree	slightly disagree	strongly disagree
13.	I like to know how committees are structured in terms of who the different committee members represent or what their functions are.	strongly agree	slightly agree	slightly disagree	strongly disagree
14.	If I had a collection (e.g. CDs, coins, stamps), it would be	strongly	slightly	slightly	strongly

	highly organised.	agree	agree	disagree	disagree
15.	I find it difficult to understand instruction manuals for putting appliances together.	strongly agree	slightly agree	slightly disagree	strongly disagree
16.	When I look at a building, I am curious about the precise way it was constructed.	strongly agree	slightly agree	slightly disagree	strongly disagree

17.	I am not interested in understanding how wireless communication works (e.g. mobile phones).	strongly agree	slightly agree	slightly disagree	strongly disagree
18.	When travelling by train, I often wonder exactly how the rail networks are coordinated.	strongly agree	slightly agree	slightly disagree	strongly disagree
19.	I enjoy looking through catalogues of products to see the details of each product and how it compares to others.	strongly agree	slightly agree	slightly disagree	strongly disagree
20.	Whenever I run out of something at home, I always add it to a shopping list.	strongly agree	slightly agree	slightly disagree	strongly disagree
21.	I know, with reasonable accuracy, how much money has come in and gone out of my bank account this month.	strongly agree	slightly agree	slightly disagree	strongly disagree
22.	When I was young I did not enjoy collecting sets of things e.g. stickers, football cards etc.	strongly agree	slightly agree	slightly disagree	strongly disagree
23.	I am interested in my family tree and in understanding how everyone is related to each other in the family.	strongly agree	slightly agree	slightly disagree	strongly disagree
24.	When I learn about historical events, I do not focus on exact dates.	strongly agree	slightly agree	slightly disagree	strongly disagree
25.	I find it easy to grasp exactly how odds work in betting.	strongly agree	slightly agree	slightly disagree	strongly disagree
26.	I do not enjoy games that involve a high degree of strategy (e.g. chess, Risk, Games Workshop).	strongly agree	slightly agree	slightly disagree	strongly disagree
27.	When I learn about a new category I like to go into detail to understand the small differences between different members of that category.	strongly agree	slightly agree	slightly disagree	strongly disagree
28.	I do not find it distressing if people who live with me upset my routines.	strongly agree	slightly agree	slightly disagree	strongly disagree
29.	When I look at an animal, I like to know the precise species it belongs to.	strongly agree	slightly agree	slightly disagree	strongly disagree
30.	I can remember large amounts of information about a topic that interests me e.g. flags of the world, airline logos.	strongly agree	slightly agree	slightly disagree	strongly disagree

31.	At home, I do not carefully file all important documents e.g. guarantees, insurance policies	strongly agree	slightly agree	slightly disagree	strongly disagree
32.	I am fascinated by how machines work.	strongly agree	slightly agree	slightly disagree	strongly disagree
33.	When I look at a piece of furniture, I do not notice the details of how it was constructed.	strongly agree	slightly agree	slightly disagree	strongly disagree

34.	I know very little about the different stages of the legislation process in my country.	strongly agree	slightly agree	slightly disagree	strongly disagree
35.	I do not tend to watch science documentaries on television or read articles about science and nature.	strongly agree	slightly agree	slightly disagree	strongly disagree
36.	If someone stops to ask me the way, I'd be able to give directions to any part of my home town.	strongly agree	slightly agree	slightly disagree	strongly disagree
37.	When I look at a painting, I do not usually think about the technique involved in making it.	strongly agree	slightly agree	slightly disagree	strongly disagree
38.	I prefer social interactions that are structured around a clear activity, e.g. a hobby.	strongly agree	slightly agree	slightly disagree	strongly disagree
39.	I do not always check off receipts etc. against my bank statement.	strongly agree	slightly agree	slightly disagree	strongly disagree
40.	I am not interested in how the government is organised into different ministries and departments.	strongly agree	slightly agree	slightly disagree	strongly disagree
41.	I am interested in knowing the path a river takes from its source to the sea.	strongly agree	slightly agree	slightly disagree	strongly disagree
42.	I have a large collection e.g. of books, CDs, videos etc.	strongly agree	slightly agree	slightly disagree	strongly disagree
43.	If there was a problem with the electrical wiring in my home, I'd be able to fix it myself.	strongly agree	slightly agree	slightly disagree	strongly disagree
44.	My clothes are not carefully organised into different types in my wardrobe.	strongly agree	slightly agree	slightly disagree	strongly disagree
45.	I rarely read articles or webpages about new technology.	strongly agree	slightly agree	slightly disagree	strongly disagree
46.	I can easily visualise how the motorways in my region link up.	strongly agree	slightly agree	slightly disagree	strongly disagree
47.	When an election is being held, I am not interested in the results for each constituency.	strongly agree	slightly agree	slightly disagree	strongly disagree
48.	I do not particularly enjoy learning about facts and figures in	strongly	slightly	slightly	strongly

	history.	agree	agree	disagree	disagree
49.	I do not tend to remember people's birthdays (in terms of which day and month this falls).	strongly agree	slightly agree	slightly disagree	strongly disagree
50.	When I am walking in the country, I am curious about how the various kinds of trees differ.	strongly agree	slightly agree	slightly disagree	strongly disagree
51.	I find it difficult to understand information the bank sends me on different investment and saving systems.	strongly agree	slightly agree	slightly disagree	strongly disagree
52.	If I were buying a camera, I would not look carefully into the quality of the lens.	strongly agree	slightly agree	slightly disagree	strongly disagree

53.	If I were buying a computer, I would want to know exact details about its hard drive capacity and processor speed.	strongly agree	slightly agree	slightly disagree	strongly disagree
54.	I do not read legal documents very carefully.	strongly agree	slightly agree	slightly disagree	strongly disagree
55.	When I get to the checkout at a supermarket I pack different categories of goods into separate bags.	strongly agree	slightly agree	slightly disagree	strongly disagree
56.	I do not follow any particular system when I'm cleaning at home.	strongly agree	slightly agree	slightly disagree	strongly disagree
57.	I do not enjoy in-depth political discussions.	strongly agree	slightly agree	slightly disagree	strongly disagree
58.	I am not very meticulous when I carry out D.I.Y or home improvements.	strongly agree	slightly agree	slightly disagree	strongly disagree
59.	I would not enjoy planning a business from scratch to completion.	strongly agree	slightly agree	slightly disagree	strongly disagree
60.	If I were buying a stereo, I would want to know about its precise technical features.	strongly agree	slightly agree	slightly disagree	strongly disagree
61.	I tend to keep things that other people might throw away, in case they might be useful for something in the future.	strongly agree	slightly agree	slightly disagree	strongly disagree
62.	I avoid situations which I can not control.	strongly agree	slightly agree	slightly disagree	strongly disagree
63.	I do not care to know the names of the plants I see.	strongly agree	slightly agree	slightly disagree	strongly disagree
64.	When I hear the weather forecast, I am not very interested in the meteorological patterns.	strongly agree	slightly agree	slightly disagree	strongly disagree
65.	It does not bother me if things in the house are not in their proper place.	strongly agree	slightly agree	slightly disagree	strongly disagree

66.	In maths, I am intrigued by the rules and patterns governing numbers.	strongly agree	slightly agree	slightly disagree	strongly disagree
67.	I find it difficult to learn my way around a new city.	strongly agree	slightly agree	slightly disagree	strongly disagree
68.	I could list my favourite 10 books, recalling titles and authors' names from memory.	strongly agree	slightly agree	slightly disagree	strongly disagree
69.	When I read the newspaper, I am drawn to tables of information, such as football league scores or stock market indices.	strongly agree	slightly agree	slightly disagree	strongly disagree
70.	When I'm in a plane, I do not think about the aerodynamics.	strongly agree	slightly agree	slightly disagree	strongly disagree
71.	I do not keep careful records of my household bills.	strongly agree	slightly agree	slightly disagree	strongly disagree
72.	When I have a lot of shopping to do, I like to plan which shops I am going to visit and in what order.	strongly agree	slightly agree	slightly disagree	strongly disagree

73.	When I cook, I do not think about exactly how different methods and ingredients contribute to the final product.	strongly agree	slightly agree	slightly disagree	strongly disagree
74.	When I listen to a piece of music, I always notice the way it's structured.	strongly agree	slightly agree	slightly disagree	strongly disagree
75.	I could generate a list of my favourite 10 songs from memory, including the title and the artist's name who performed each song.	strongly agree	slightly agree	slightly disagree	strongly disagree

Appendix 6. MEG Pre-Scan Information & Safety Questionnaire

MEG Pre-Scan Information

WHT IS MEG?

Magnetoencephalography (MEG) is a safe, non-invasive and entirely passive human brain imaging technique. The MEG scanner measures the very small magnetic fields outside the head - these arise naturally from electrical activity within the brain.

IS THERE ANY PREPARATION?

The MEG instrument is extremely sensitive to metallic objects entering the shielded room. Hence, you could assist us by:

- wearing clothing that does not have metal fastenings;

- not wearing any jewellery, and

- removing all eye make-up (as this can interfere with scans of the head).

You will also be required to complete a MEG safety questionnaire before your scan.

CAN ANYONE HAVE A MEG SCAN?

No. There are some pre-conditions which can damage the MEG scanner. The MEG scanner is extremely sensitive to the presence of metallic objects, either permanently or temporarily carried in or near to your body. These conditions will be rigorously screened for during your pre- assessment for MEG scanning. Having metallic objects on your person, although not a danger to you, may cause damage to our equipment.

IS AN MEG SCAN SAFE?

MEG scanning has been in use as a medical imaging and research tool for many years and is commonly regarded by clinicians and scientists as a safe procedure. It does not employ ionising radiation (such as x-rays) and hence does not pose an additional cancer risk. The researchers on duty will answer any queries you might have on the day, or if in doubt, please call the chief investigator.

WHAT WILL HAPPEN WHEN I ARRIVE?

The researcher will greet you at the MEG unit waiting room and reception, explain the procedure and ask you questions about previous surgery you may have had regarding implanted metal in your body. You will be asked to leave your valuables (coins, keys, watch, jewellery, credit cards, mobile phones, pagers etc.) in a locker. The researcher will guide you to the magnetically shielded room housing the MEG scanner. Some equipment may be placed around you whilst scanning; this may include headphones and/or a stimulus screen.

THE SCANNING PROCESS

When we are taking the pictures, we will ask you to keep as still as possible. Usually there will be about 4 or 5 different scans, lasting for 2-8 minutes each; and for most studies you will be in the scanner for about 60 minutes. For some studies you are welcome to bring along your favourite CD or cassette to listen to, during your scan, please ask your researcher.

WHAT WILL HAPPEN AFTER THE SCAN?

You can leave immediately after your scan. The images that have been taken will be used to address the research question for the study you have agreed to take part in.

MEG Pre-Scan Safety Questionnaire

This questionnaire is designed to screen for various conditions in a potential MEG participant. It is VERY important that you complete it as honestly and comprehensively as possible – please ask if you have any questions. This form is to be completed under the supervision of a staff member **PRIOR** to entering the MEG room. Note that answering YES to any of the questions does not automatically disqualify a person from having an MEG scan.

Please answer YES or NO to the following: *Please circle*

Have you ever done or been near welding? ………………………………………………………………………………
YES / NO Have you ever been injured by a piece of metal that has not been removed (bullet/shrapnel)?
…………… YES / NO Do you know of any metal that has been implanted into your eye, skin or body at anytime? ……………… YES / NO Do you have any of the following:

Aneurysm clip (on a blood vessel) …………………………………………………………………………
YES / NO Ocular / eye implant ……………………………………………………………… YES / NO Cochlear / ear implant ……………………………………………………………. YES / NO Hearing aid (removable) ………………………………………………………………………… YES / NO Cardiac pacemaker/pacing wires or implanted cardioverter defibrillator ……………………………… YES / NO Artificial heart valves ……………………………………………………………………….. YES / NO Other implanted electronics devises (bone growth, neurostimulator) ……………………………… YES / NO Implanted infusion or drug pump ……………………………………………………………… YES / NO Hip replacement or artificial joint or artificial limb ……………………………………… YES / NO Pin, plate or screw attached to a bone ……………………………………………………. YES / NO Implanted coil, filter, shunt or stent ………………………………………………………………… YES / NO IUD, diaphragm, or pessary ……………………………………………………………… YES / NO Non-removable piercings or jewellery ……………………………………………………. YES / NO Permanent make up …………………………………………………………………………… YES / NO Medication patches (Nicotine, Nitroglycerine) ………………………………………… YES / NO Dental bridge; partial plates; permanent retainer; temporary spacers ……………………… YES / NO Crowns on teeth; posts in teeth ……………………………………………………. YES / NO Dental implants …………………………………………………………………………. YES / NO

Have you ever had a surgical operation? …………………………………………………………………………
YES / NO If yes, please provide details of body area (head, arm) and medical condition

……
…………… Approximately how many fillings do you have? ………………….

Do you have any allergies? ……………………………………………………………………………………………..
YES/NO

If   yes,   details:
……

Consent

I have read the above information and am aware of the processes involved in an MEG examination. I have been provided with the opportunity to have any questions answered and I therefore give my consent to an MEG scan. I confirm that the questions have been answered to the best of my knowledge.

STUDY/PROJECT NAME: …………………………………………………………………………………………..

PARTICIPANTS NAME…………………………………………………………………………………………….

SIGNATURE: ……………………………………………………………………….DATE: ……/……./…….

MEG RESEARCHER NAME: ……………………………………………………………………………………

SIGNATURE: ……………………………………………………………………….DATE: ……/……./…….

MEG Personal Preparation

Preparing for your MEG Scan

On the day of your MEG scan, we request that you take the following steps:

1) Please empty your pockets of all magnetic items including wallet, bank cards and coins. You will also need to remove any jewellery you have on.

2) Do not wear make up.

3) (If applicable) Do not wear an underwire bra (sports bras that have no underwire are fine).

4) If you wear eye glasses you will not be able to wear them in the MEG scanner. Immediately prior to entering the MEG we can provide you with MEG compatible glasses. If you bring your prescription or know your prescription this will help us to give you the best temporary glasses for your scan. Contact lenses are fine for MEG scans.