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COGNITION AND THE STEADY STATE
VISUALLY EVOKED POTENTIAL

PER LINE
M.App.Sc
1993
ACKNOWLEDGMENTS

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ABSTRACT

This masters thesis examines the hemispheric activation pattern of the cognitive processes involved in a complex mental rotations test (MRT) (Vandenberg and Kuse, 1978) using Steady-State Probe Topography (SSPT) (Silberstein et al, 1990) as a method to index brain activity. The Steady State Visually Evoked Potential (SSVEP) was recorded from 64 electrode sites using a multichannel electrode helmet, and elicited by a 13 Hz sinusoidal visual flicker, whilst the subjects were performing a visual vigilance Baseline task and the MRT. Forty-one right handed subjects (twenty male and twenty-one female) were used. In the MRT the subjects were required to choose the two figures which correctly matched the criterion figure in the centre. The figures were three-dimensional objects represented in two-dimensions on a computer screen. A significant finding of this study was that when all the subjects were considered as one group, no noticeable lateralization in cerebral activation associated with mental rotation was evident. When analyzing the results for the subjects, partitioned into two groups according to gender, evidence was found suggesting that the cortical processing associated with mental rotation may be more localized bilaterally in the males than the females. However, no noticeable lateralization effects for mental rotation were found in the males or females, and hence no gender differences in hemispheric lateralization was evident. An important finding was the emergence of gender differences in hemispheric lateralization in subsets of subjects performing with higher spatial ability. A left hemisphere lateralization for mental rotation was associated with the Best Performance Male group. The Best Performance Female group showed the opposite effect, where a right hemisphere lateralization was associated with better performance on the task. The lateralization effect appeared to be stronger in the Best Performance Males than the Best Performance Females. An important conclusion from this study is that when examining for hemispheric lateralization effects in mental rotation, and possibly other visual-spatial tasks, not only gender effects need to be considered, but the level of spatial ability in the comparison groups needs also to be taken into account.
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CHAPTER 1

INTRODUCTION
1.1 INTRODUCTION

The subject of human brain asymmetry has attracted a lot of interest in recent times. The amount of data gathered "indicating reliable right-left neuroanatomical asymmetry is impressive" (Witelson and Kigar, 1988, p.111). Whilst the study of neuroanatomical asymmetry gained renewed interest after a paper by Geschwind and Levitsky (1968) on asymmetry in the Sylvian fissure region, the study of functional asymmetry started in earnest after World War II, when it was "realized that some behaviours were more affected by right-hemisphere damage than by left-hemisphere damage" (Bryden, 1988, p.143). Of particular interest has been the idea that the left hemisphere is specialized for language functions, and that the right hemisphere is specialized for non-verbal functions, such as visuospatial processing (Bryden, 1988).

Some visuospatial tasks, particularly those involving mental rotation, are associated with a degree of uncertainty as to which hemisphere is actually specialized for mediating the cognitive processing of the spatial task (Fischer and Pellegrino, 1988). The confusion is illustrated by some studies indicating a superior role for the left hemisphere in mental rotation (Mehta and Newcombe, 1991; Mehta, Newcombe and Damasio, 1987; Fischer and Pellegrino, 1988; Corballis and Sergent, 1989; Ornstein et al, 1980), whereas other studies indicate a superior role for the right hemisphere in mental rotation (Deutsch et al, 1988; Ditunno and Mann, 1990; Papanicolaou et al, 1987, Corballis and Manalo, 1993). Other experiments involving mental rotation have failed to find any significant difference in hemispheric dominance (Gevins et al, 1979; Jones and Anuza, 1982), whilst another study has found visual field differences for clockwise and counter-clockwise mental rotation (Burton et al, 1992). Hence, the words of Burton et al (1992), that "the nature of hemispheric specialization for mental rotation is unclear" (p.192), seems to accurately convey the current consensus on the subject.

To help resolve the nature of hemispheric specialization for mental rotation, the hemispheric lateralization for mental rotation was investigated using a new brain mapping technique known as Steady State Probe Topography (SSPT). SSPT has been developed at the Swinburne Centre for Applied Neurosciences (SCAN) (Silberstein et al, 1990). Other electrophysiological studies have usually involved looking at transient evoked potentials (EPs) or ongoing electroencephalogram (EEG) analysis (Ray et al, 1981; Gevins and Cutillo,
1986). A more detailed exposition of the SSPT technique is given in Chapter 3. A detailed outline of the hypothesis to be tested is also given in Chapter 3.

In this study the cognitive processes associated with the Vandenberg and Kuse (1978) mental rotations test was investigated. Because the emphasis of the study was on the long term tonic effects of mental rotation, the complexity of the Vandenberg and Kuse mental rotations test was adjudged to be a suitable task for this purpose. Each item in the Vandenberg and Kuse mental rotations test consists of a criterion figure, two correct alternatives, and two incorrect alternatives. The correct alternatives are identical to the criterion figure, but are presented in a rotated position. To choose the correct alternative, the subject has to match each object with the criterion figure, and this is usually done by trying to visualize the two-dimensional presentation of the object as being rotated in three dimensions.

The Vandenberg and Kuse (1978) mental rotations test is known to produce larger cognitive sex differences in performance than any other test of spatial ability, "yielding consistently higher male performance" (Goldstein, Haldane and Mitchell, 1990, p.547). These sex differences are best found when the test is given under conditions with strict time limits and when raw scores are calculated. "With no time limit or with the use of ratio scores", it has been reported that "the sex difference is not found" (ibid p.549). Hence, in this study, strict time limits were used, not only to look for sex difference in performance, but also to ensure that the subject was continuously engaged in the task during most of the recording period.

The main emphasis of this study was on the investigation of hemispheric lateralization effects during the mental rotation task. Chapter 2 comprises a literature review dealing with the topic of electrophysiological correlates of visual-spatial function, as well as an overview section that provides a background on visual spatial function, with particular emphasis on sex differences in human brain asymmetry as this may be a confounding factor.

Methodology is described in Chapter 4, which gives an outline of the procedure used in the experiment, giving details of the recording procedure, tasks used, data analysis, etc., whilst Chapter 5 presents the relevant results. The discussion is given in Chapter 6, which is followed by the appendices in Chapter 7 and bibliography in Chapter 8. A glossary is provided in Appendix 7.1 (Chapter 7) which refers the reader to the section in the thesis where each particular term or abbreviation is defined.
CHAPTER 2

LITERATURE REVIEW

ELECTROPHYSIOLOGICAL CORRELATES OF VISUAL-SPATIAL FUNCTION
2.1 INTRODUCTION

This literature review is divided into two main parts, consisting of a core section and an overview section. The core section is a detailed literature review on electrophysiological correlates of visual-spatial function. The core section is divided into two main parts. The first part deals with the ongoing electroencephalogram (EEG) and the second part deals with event related potentials (ERPs). This provides background knowledge for the experiment undertaken in this thesis, which examines mental rotation and hemispheric engagement using a new technique known as Steady State Probe Topography (SSPT).

The main purpose of the overview is to provide a background on visual-spatial function, using sex differences in human brain asymmetry as a theme. The reason for using gender effects as a theme is that, if there is a sex difference in human brain asymmetry, then this will confound the results of any experiment that does not take this factor into account. Sex differences in functional and neuroanatomical asymmetry is examined, as is hormonal influences in the cognitive processing of visual-spatial tasks. Also, a discussion on sex differences in behavioural performance with regards to visual-spatial ability is included.

Not only sex differences will be discussed in the overview, however. The role of the hemispheres in visuospatial processing, particularly pertaining to mental rotation (see Section 2.2.8), will also be considered, as well as any other information considered relevant in this context, as it provides a foundational framework which is often necessary when trying to interpret or understand the data with regards to lateralization effects. More emphasis will be placed on discussing mental rotation, where applicable, than other visual-spatial tasks, as the mental rotation task is the main focus of this thesis. A summary of the main findings from this literature review is presented in Section 2.4.

2.2 OVERVIEW

When trying to isolate a particular factor or influence that is responsible for possible cognitive differences between males and females, one becomes aware that there may be several factors that contribute to sex differences. There are biological and environmental factors to consider. The biological factors are considered to be genetic influences, hormonal influences and neurological
influences. Neurological influences include any "neuroanatomical differences in the structure, organization, and/or function of the brain" (Halpern, 1986, p.68).

If neurological influences are to be considered relevant, then one would first have to show that the structure, organization, and/or function of the human brain is dimorphic with respect to gender. Sex differences in human brain asymmetry does not, however, necessarily infer cognitive sex differences. Sex differences in human brain asymmetry need to be correlated with performance in cognitive tasks, in order for neurological influences to be considered as a biological factor contributing, in whole or in part, to cognitive sex differences. There has already been several reviews dealing, either partly or exclusively, with the subject of sex differences in human brain asymmetry (Buffery and Gray, 1972; McGlone, 1980; Fairweather, 1976; Bradshaw and Nettleton, 1983; Harris, 1978; Halpern, 1986).

### 2.2.1 Visual-spatial ability

When looking at gender effects with respect to cognitive processes, one of the most detailed and documented abilities that have been examined is visual-spatial ability. Hence, in this section some of the findings with regards to behavioural performance sex differences in visual-spatial ability will be reviewed, as well as a discussion dealing with some of the more common visual-spatial tasks that are known to yield sex differences.

One of the most comprehensive reviews of the literature on sex differences was published by Maccoby and Jacklin (1974). One of the findings that emerged from their study was that "male superiority on visual-spatial tasks is fairly consistently found in adolescence and adulthood, but not in childhood" (p.351). There has been several monographs written on the subject of sex differences in cognition since Maccoby and Jacklin published their book in 1974. McGuinness (1976) concluded in her review that "men excel in visual-spatial ability, and this can be demonstrated in a number of tasks" (p.138). She cited the Rod-and-Frame test as an example. In a more recent review Halpern (1986) stated that "findings of sex differences in visual-spatial ability are the most robust of the cognitive sex differences. It also appears that the largest sex differences are found here" (p.62).

Other reviews have also supported the findings that men perform better than women in visual-spatial tasks (see Harris, 1978; Bradshaw and Nettleton, 1983; McGee, 1979; Newcombe, 1982). Fausto-Sterling (1985) acknowledges
that "sex differences in spatial visualization do sometimes exist, even if they don't amount to much" (p.33). Fairweather (1976) concedes that "there is, finally, good evidence of a clear, adult, male superiority for a small nucleus of definitive spatial skills" (p.256), but her review basically argues against there being any convincing evidence of sex differences in cognition.

In a "multilevel critique" Caplan, MacPherson and Tobin (1985) answered the question of the existence of sex-related differences in spatial abilities by stating that "the answer is 'No, sex differences in spatial abilities do not exist' or at least 'It is by no means clear as yet'" (p.797). Likewise, Hyde (1981) has also cast doubt on the significance of gender differences in both visual-spatial and verbal abilities. However, a meta-analysis investigating the emergence and characterization of sex differences in spatial ability did find evidence "that sex differences arise on some types of spatial ability but not others" (Linn and Petersen, 1985, p.1479). Elsewhere, Linn and Petersen (1986) have stated that gender differences in spatial ability "occur primarily on tasks where efficient solution requires rapid manipulation of symbolic information or on tasks that require recognition of the vertical or horizontal. Tasks that rely on symbolic information but require analytic strategies do not appear to yield gender differences" (p.74-75). A recent study by Oosthuizen (1991) has added further support for the existence of sex-related differences in spatial ability, with men performing better than women.

Hence, there is strong evidence from the literature that sex differences in visual-spatial abilities exist, with men usually having superior abilities than women. However, at present this notion seems to still be the topic of fierce debate (Holden, 1991). The questions in need of answering are the magnitude of the difference and the type of spatial skills that give evidence of there being any significant sex differences. Even more controversial is the characterisation of what type of factors contribute to the differences in visual-spatial skills.

A general definition of visual-spatial ability states that "it refers to the ability to imagine what an irregular figure would look like if it were rotated in space or the ability to discern the relationship among shapes and objects" (Halpern, 1986, p.48). Visual-spatial ability is considered to be determined by two separate factors, known as spatial visualization and spatial orientation (McGee, 1979). "Spatial visualization involves the ability to mentally rotate, manipulate, and twist two- and three-dimensional stimulus objects" (McGee, 1979, p.896), whereas "spatial orientation involves the comprehension of the
arrangement of elements within a visual stimulus pattern, the aptitude to remain 
unconfused by the changing orientations in which a spatial configuration may be 
presented, and the ability to determine spatial orientation with respect to one's body" (ibid p.897).

Shepard and Metzler (1971) introduced the mental rotations test (MRT), 
which is very commonly used in assessing visual-spatial ability. The MRT 
involves having subjects try to determine whether two two-dimensional pictures 
represent identical three-dimensional shapes when the objects are portrayed in 
different orientations. The reaction times of the subjects can then be compared 
with the angular difference in the orientations of the three-dimensional objects. 
The pictures can differ by rotation in the picture plane or a more complex rotation 
in depth. Vandenberg and Kuse (1978) developed the MRT further by including 
four two-dimensional projections of three-dimensional objects, in addition to the 
criterion figure. They developed the stimuli used by Shepard and Metzler into a 
paper-and-pen test of spatial visualization. Male performance on this test has been 
described as "yielding consistently higher male performance" and "larger sex 
differences have been found with this test than with any other test of spatial 
ability" (Goldstein, Haldane and Mitchell, 1990, p.547; see also Sanders, Soares 
and D'Aquila, 1982; Sanders and Soares, 1986).

A study by Casey (1992) on 71 high school students (freshmen through 
seniors) found that sex differences in mental rotation ability was evident across a 
range of races and social class groups. It was found that the minority high school 
boys had a substantially higher mental rotation ability than the girls. In contrast to 
this finding, Pezaris and Casey (1991) found no significant difference on the 
mental rotation task between the boys and the girls. A total of 180 right handed 
subjects (102 girls, 78 boys, mean = 13 years 10 months) were used in the study. 
They explained the discrepancy in their results from the main body of literature 
by suggesting that perhaps adolescent boys are more easily distracted and do not 
try as hard as their older counterparts (adult males). They also suggested that 
early adolescent subjects lack the necessary environmental experiences to develop 
their mental rotation abilities to their fullest. Another study by Casey, Pezaris and 
Nuttall (1992), on subjects of a similar age group, also found no significant effect 
of sex on the performance of mental rotation. A meta-analysis by Linn and 
Petersen (1985) found "that large sex differences are found only on measures of 
mental rotation" (p.1479).
The Rod and Frame Test requires subjects to position a rod in the true vertical position, with the rod being located within a tilted rectangular frame. This test is frequently interpreted in terms of field dependence and field independence. If the tilt of the rectangular frame influences the subject's judgement of the true vertical position of the rod, then the subject is labelled field dependent. If the tilt of the frame does not effect the subject's judgement of the true vertical position, then the subject is labelled field independent (see Halpern, 1986, p.53). In a review of some of the studies involving the Rod and Frame Test, McGee (1979) concluded that "adult females tend to be more dependent on the field in determining the vertical position of the rod than males" and "the sex difference is apparent in adolescents as well" (p.897). With regard to sex differences the usual finding is that men perform significantly better on the Rod and Frame Test than the women (see for example Allen and Hogeland, 1978).

The Embedded Figures Test is another field dependent and field independent test which is known to show clear sex differences in adults and adolescence, with males showing more field independence than females (Halpern, 1986; McGee, 1979). Hence, males usually perform better than females on this test (see for example Parlee and Rajagopal, 1974). It has been argued that field dependence can be correlated with spatial orientation, and so reflect sex differences in visual-spatial ability. In the Embedded Figures Test the subject is required to remember a simple geometric form that has been visually presented, and then to recognise it when it is hidden away in a more complex geometric form.

The Water Level Test is a visual-spatial task in which sex differences are reliably found. Devised by Piaget and Inhelder (1956), it is based on the knowledge that the water level will remain horizontal in a bottle when the bottle is tipped. It was believed by Piaget and Inhelder (1956) that this principle would be mastered around the age of 12, but it was found in subsequent studies that girls recognised this principle at a later age than boys did (Harris, 1978). The finding that men are more accurate in performing this task than women has been reproduced in numerous studies (for example Kalichman, 1986; see Harris, 1978 for a review).

Another task associated with sex differences in visual spatial ability, which has been known to yield better male performances, is the Line Orientation Task (Benton, Varney and Hamsher, 1978). In this task the subject is required to name the two lines, in the response choice display of eleven lines, which correspond to
the two stimulus lines. The two lines in the response choice display need to occupy the same location and have the same angles as the two stimulus lines. The task is made more difficult if the two stimulus lines are reduced to only half the length of the lines in the response choice display.

2.2.2 Tachistoscopic experiments

The tachistoscope is a device which presents very brief visual stimuli to the left or right of the point of fixation. The purpose of this is to allow only one side of each retina, and hence only one cerebral hemisphere, to be directly stimulated (Kimura, 1973). The point of fixation is a fixed point on the tachistoscope, which the subject is asked to fixate straight on. Because the visual stimulus is presented very rapidly, the subject has not sufficient time to change his fixation, from the point of fixation to the visual stimulus presented. The nature of the visual pathways is such that the "nerve fibers from the left half of each eye connect to the left hemisphere and nerve fibers from the right half of each eye connect to the right hemisphere" (Halpern, 1986, p.78). Hence, this allows one to determine which hemisphere is initially activated during a tachistoscopic experiment. A visual stimulus presented in the left visual field will directly activate the right hemisphere, and a visual stimulus presented to the right visual field will directly activate the left hemisphere. Some experiments use computer screens or slide projectors to present the stimuli to the subject, but essentially carry out the same function as a two-field tachistoscope. In the context of this review these studies will be treated as tachistoscopic experiments.

One type of visual stimulus used is that of visual-spatial stimulus; for example, recognizing a face, the location of a single point (dot) in a two-dimensional area, or looking at depth perception by viewing a movable rod with respect to a stationary one (see Kimura, 1973). Variants also use verbal material, such as words and letters. With visual verbal stimuli, right handed subjects usually perform better when the stimuli is presented in the right visual field, which is interpreted as indicating a left dominant hemisphere for verbal tasks. When visual-spatial stimuli are presented to the subject, the visual-spatial tasks are usually performed better when the stimuli is presented to the left visual field, indicating a right hemisphere dominance for visual-spatial tasks (Kupfermann, 1985; Kimura, 1973; French and Painter, 1991).
In a tachistoscopic study, Servos and Peters (1990) found a clear left hemisphere advantage for spatially based verbal categorization, which is not predictable from the spatial feature of the stimuli used. In fact, the authors begin their paper by commenting that "in the neuropsychological literature, there is no longer any certainty with regard to right hemisphere (RH) specialization in the domain of 'visuo-spatial' function" (p.1251).

A study by Fischer and Pellegrino (1988) also produced a left hemisphere superiority on the performance of a mental rotation task, involving the rotation of eight uppercase alphanumeric characters and eight two-dimensional figures from the Primary Mental Abilities Test. They noted that the faster response times recorded from the right visual field, of approximately 20 msec, were comparable to estimates of corpus callosum transfer time, hence suggesting that the delay in left visual field processing time could be due to information being transferred to the left hemisphere. They hypothesised that one or more components of the mental rotation task performance may be differentially processed by the hemispheres.

A study by Corballis and Sergent (1989) also found a right visual hemifield advantage in reaction time for a mental rotation task. Their subjects had to decide whether rotated letters, flashed in the left or right visual field, using Apple IIE microcomputers with fast decay screens, were normal or reversed. A similar type study by Corballis and Manalo (1993), which examined the effect of spatial attention on mental rotation, showed "no evidence that spatial attention affected mental-rotation rate" (p.199), however, the mental rotation rate "was higher when attention was to the left side of space, consistent with right hemispheric specialization for mental rotation" (ibid p.199).

There are other tachistoscopic studies that have also found greater right hemisphere involvement for mental rotation (Ditunno and Mann, 1990). A study by Jones and Anuza (1982) found no visual field advantage for a mental rotation task, and neither was there evidence of a sex difference in lateralization. In addition, there are studies that further confound the issue. For example, a study by Burton et al (1992) found visual field differences for clockwise and counter-clockwise mental rotation in a tachistoscopic experiment. Their study suggested that clockwise rotations were more readily performed in the left visual field, whereas counter-clockwise rotations were more readily performed in the right visual field.
Hatta (1978) found a left visual field superiority when watch figure stimuli were presented tachistoscopically and subjects (12 males, 23 females) were asked to read the time. However, this left visual field superiority could be changed to a right visual field superiority by imposing a mental transformation task upon the watch figure recognition task. Hatta noted that the result of the study "strongly suggests that the left hemisphere plays a predominant role in the performance of a task including some higher mental processing" (p.640).

Support for the assertion that male brains are more lateralized than female brains can be found in tachistoscopic studies, according to Halpern (1986). She stated that "males show greater right visual field superiority for verbal materials (Day, 1977), and greater left visual field superiority for spatial stimuli (Kimura, 1969; Kimura and Durnford, 1974)" (p.82). In her review, McGlone (1980) noted that "many recent tachistoscopic studies have indicated that laterality effects for both verbal and nonverbal material differ significantly between sexes" (p.220). She noted a right field superiority for alphabetic material in males, and a left field superiority in males for the perception of photographed faces, the detection, localization, or enumeration of scattered dots, as well as for line orientation.

Harrison, Gorelczenko and Cook (1990) showed in a study that "men were significantly faster in processing affective facial information within the left visual field" (p.1). Fairweather (1976) argued that there is insufficient evidence in tachistoscopic studies to support the notion of sex differences. In a review on adult visual studies Bryden (1979) concluded that, for nonverbal studies, the evidence for a left visual field (LVF) superiority was not strong, but that "the majority of studies seem to suggest that males are more likely than females to show an LVF superiority" (p.132).

In a study by Kail and Siegel (1978) arrays of four digits were presented to the left or right visual field of the subjects for 80 msec (18 males, 18 females). Visual field differences in recall of digits was found in the males only, indicating that left hemisphere specialization for processing verbal information was greater in males than in females. Both males and females recalled the positions of the digits equally well when they were presented to the left and right visual fields. Overall, the males' recall of positions was superior to the females, and the females' recall of digits was superior to the males, indicating a sex difference in verbal and spatial memory.
A study by Martin (1978) found that females performed consistently faster than males on both a visual and verbal task (6 males, 6 females), irrespective of decision type or hemisphere, though the difference did not reach significance due to a large amount of variance. The task required a yes-no comparison of letters presented to the left and right visual fields. The visual task involved detection of curved letter segments and the verbal task involved detection of rhyming "ee" sounds. For "yes" decisions, females were faster in the right hemisphere than in the left, whilst the opposite was true for the males. Also for females, "no" decisions were faster than "yes" decisions in the left hemisphere, but the reverse was true for the right hemisphere. No such differences were found for the males. From this experiment Martin suggested "that differences in cognitive function exist between men and women and that these differences are dependent upon differential hemispheric specialisation" (p.232).

A study by Voyer and Bryden (1990), involving 24 males and 24 females performing a lateralized two-dimensional rotation task presented on a Commodore colour monitor, found a significant spatial ability by visual field interaction. The performance of the subject on the Vandenberg and Kuse Mental Rotations Test (Vandenberg and Kuse, 1978) was the criteria for assessing the subjects' level of spatial ability. A tachistoscopic type study was then carried out on a different mental rotation task, using figures from the Primary Mental Abilities (PMA) test. Results suggested that subjects with high spatial ability had a right field advantage whereas subjects with medium spatial ability had no field advantage and subjects with low spatial ability had a left field advantage. The gender by visual field interaction supported the notion "that specialization of the right hemisphere for spatial functions is greater for males than for females" (p.25). It was found that, with regards to reaction time, males showed a significant left visual field advantage, whereas females showed a marginally significant right visual field advantage. The reaction times of the females were found to be significantly faster. No significant effect of sex and accuracy was noted. Voyer and Bryden commented that the findings of their study "provides support for the hypothesis that the right hemisphere has a greater ability to process novel stimuli, while the left hemisphere is superior at utilizing familiar stimuli" (p.25). Hence, if high spatial ability subjects are more familiar with mental rotation, and if the left hemisphere is superior at processing familiar stimuli, then it would explain why high spatial ability subjects show a left hemisphere advantage.
There are a number of studies supporting the finding of a greater right hemisphere lateralization in males for visual-spatial tasks (e.g. McGlone and Davidson, 1973; Sasanuma and Kobayashi, 1978; Segalowitz and Stewart, 1979). However, as seems so often to be the case when studying gender effects in cognitive processes, the existence of contradictory findings, where there were no effects of sex (e.g. Leehey et al, 1978; Bryden, 1976), is a caution against being too confident in interpreting the available data in this area.

To conclude this section on tachistoscopic experiments, a quote from Servos and Peters (1990) is applicable: "Neuropsychological work is often criticized because it lacks a sound theoretical foundation. However, adequate theories can only be formulated if a minimal understanding of the phenomena one wishes to account for is available. We maintain that particularly in the area of lateralization of 'visuo-spatial' functions we do not yet possess such minimal knowledge and that we are still at an exploratory stage" (p.1258).

2.2.3 Anatomical studies

Various brain mapping techniques are available to study various aspects of the brain (Begley et al, 1992). Computerized tomography (CT) scans and magnetic resonance imaging (MRI) are useful in studying the structure of the brain, but does not allow one to explore the function of the brain (Martin and Brust, 1985; Drayer, 1988), although recent developments has led to the introduction of functional MRI (Luiten, 1992). In examining for neuroanatomical asymmetries MRI and CT scans are very useful and are the two main techniques used, apart from making direct measurements from autopsy samples.

Anatomical asymmetries between the right and left hemispheres of the human brain, it has been argued, "may be the basis for the development of functional hemispheric specialization" (McGlone, 1980, p.221). Geschwind and Levitsky (1968) reported that the left planum temporale, which forms part of Wernicke's speech area, was significantly larger in 65 out of 100 adult brains. Similar findings of a larger left planum temporale has also been found by others (see Witelson and Pallie, 1973; Wada, Clarke and Hamm, 1975; Rubens, Mahowald and Hutton, 1976).

Whilst some work has been done on right-left asymmetries of the brain, evidences of sex differences in human brain morphology is less clear, "since most investigations have overlooked the possibility of sex differences in morphological
asymmetries" (McGione, 1980, p.223). Landsell (1964), in speculating about sex differences in cerebral asymmetry, suggested that the differences in venous drainage "was related to the superiority of girls over boys in certain verbal skills" (p.550). In their review Buffery and Gray (1972) stated that "there are sex differences in a variety of asymmetries of cerebral structure" (p.146). In another review Bryden (1979) commented that "while there are certainly signs of sex-related differences in several studies, the small sample sizes and great variability preclude any statistical significance" (p.136). Very little was said about any anatomical evidence of sex difference in adult brains by Harris (1978). He noted that "whether, as we might suppose on the basis of Buffery and Gray's model, there is greater planum asymmetry in young females than young males is uncertain" (p.455).

In introducing their study, de Lacoste-Utamsing and Holloway (1982) noted that "to our knowledge no reliable sex differences in human brain morphology have been evidenced to date" (p.1431). In their study, however, they found evidence of a sex difference in the shape and surface area of the human corpus callosum. They observed that "the sexual dimorphism is striking in the splenium, the caudal or posterior portion of the corpus callosum. The female splenium is both more bulbous and larger than the male counterpart" (p.1431). They stated that "since peristrate, parietal, and superior temporal fibers course through the splenium, this finding could be related to possible gender differences in the degree of lateralization for visuospatial functions" (p.1431). They surmised that if a larger splenium indicates that more fibers are interconnecting cortical areas, and that lateralization of hemispheric specialization of function is correlated inversely with the number of interhemispheric fibers, then their results supported the hypothesis that the female brain is less well lateralized than the male brain for visuospatial functions.

Telencephalic structures such as the massa intermedia, anterior hypothalamus and anterior commissure are established as being sexually dimorphic according to de Lacoste, Adesanya and Woodward (1990). In their study they were able to document human brain sexual dimorphism while at the same time taking into account the gender related variance in brain weight. They stated that "the surprising result described here is that many measures, when divided by brain weight, become more rather than less significant with respect to dimorphism" (p.932). In relation to gross brain weight they interpreted some of their gender difference findings as being due to simply gender differences in brain
weight, but that other measures which were sexually dimorphic independent of brain weight indicated that there was "underlying differences in the anatomical organization of the brain" (p.937). In relation to the corpus callosum they found evidence confirming previous studies that, relative to brain weight, the corpus callosum was larger in females than in males.

A study looking at possible sex differences in the developing human fetal brain was undertaken by de Lacoste, Horvath and Woodward (1991). They found that, on average, fetal male brains favoured the right hemisphere in volumetric asymmetries, whereas fetal female brains were likely to have two hemispheres of the same size or a slightly larger left hemisphere relative to the right hemisphere. They tended to rule out the possibility of a sex difference in maturation rate as accounting for the findings of their study.

The absolute volume of the human brain is significantly larger in males by about 10 to 15 percent (Witelson, 1985). In a study, Witelson (1985) found that the corpus callosum, which is the "main fiber tract connecting the two cerebral hemispheres", was larger by about 11 percent "in left-handed and ambidextrous people than in those with consistent right-hand preference" (p.665). However, "no sexual dimorphism in size of the callosum was observed" (p.666). When brain size was taken into account, there were still no significant sex differences.

A study on the effects of handedness and sex on the morphology of the corpus callosum was carried out by Habib et al (1991). They obtained their callosal area measurements on 53 normal subjects (35 males; 18 females) from midsagittal MRI images. They found a significant effect between handedness and the size of the midsagittal callosal area, but no significant effect of gender alone, whether it be the total callosal area or any of the six subregions measured. They found, however, an effect of gender on handedness/callosal size. The relationship between handedness and total callosal area seemed to be specific to males only. The consistent right handed males had a smaller total callosal area, with the difference being larger in the anterior half of the corpus callosum. In the females, the posterior body of the corpus callosum was found to be larger in the consistent right handed female group. These results "suggests a reversed effect of handedness on callosal size in females and males" (p.57).

A study by Allen and Gorski (1986) examined sexual dimorphism of the human anterior commissure. They found that after adjustments were made for sex differences in brain weight, the anterior commissure in the female was 36% larger
than in the male. Without the adjustment in brain weight the anterior commissure was still larger by 19% in the female.

Yoshii et al (1986) found no evidence of a sex difference in any of the corpus callosum measurements they made, but a study by Kertesz et al (1986) did find a significant sex effect. They found that "the area of corpus callosum in women is relatively larger when their smaller brain size is taken into consideration" (p.316), but the absolute area of the corpus callosum was larger in the males. A study by Bear et al (1986) found significant sexual variation in human cerebral asymmetries, with enhanced right frontal and left occipital predominance being shown by male subjects. The 66 subjects were adult outpatients with no diagnostic abnormalities, who underwent computed tomography scans.

A factor analysis of the human corpus callosum was undertaken by Denenberg, Kertesz and Cowell (1991) using a recently developed computer program. Among their findings was that in the posterior body of the corpus callosum, in the isthmus area, the males had wider callosa than females. A study by Hauser et al (1989) showed a trend for female controls to have a thicker anterior callosal width than male controls. Also found was that male controls had a significantly larger splenium to total callosal area than the female controls. The study was on corpus callosum dimensions measured by MRI in bipolar affective disorder and schizophrenia, but the findings of gender differences in the callosal area of the male and female control groups were the most interesting.

Using MRI Allen et al (1991) "observed that the shape of the splenium was consistently wider or more 'bulbous' in females than in males" (p.941), but in 23 measurements of the areas and subdivisions of the corpus callosum only one division, located in the posterior region, showed a significant sex difference. In an autopsy sample of human brains Clarke et al (1989) found that females tended to have a smaller cross-sectional callosal area, a more slender corpus callosum, a larger fraction of corpus callosum area in the posterior fifth of the corpus callosum, and more bulbous splenium. A study by Witelson (1991) found that the callosal area decreased with age throughout the callosum in men, but in women there was minimal correlation between the callosal area and age.

Although more work on gender differences in the human brain has been done since 1980, and there appears to be some evidence of a genuine sex difference, it would be premature at present, as it was for McGlone in 1980, to make any definite conclusions. This is especially true when attempting to interpret
the functional significance of any sex difference in human brain morphology, and is echoed by de Lacoste-Utamsing and Holloway (1982) when they conclude by saying that "we await quantitative ultrastructural information on the relative numbers and density of myelinated and unmyelinated fibers in the splenium as well as more refined neuropsychological tests before we can interpret further this correlation of our anatomical finding with neuropsychological observations" (p.1432). Among the reasons given for being cautious in the interpretation of findings is that large variations in callosal shape and size exist among individuals (Bleier, Houston and Byne, 1986).

In a paper by Gibbons (1991) she stated that "although evidence of anatomical differences between male and female brains is accumulating fast, many researchers think the surface has barely been scratched" (p.959). She mentioned the hippocampus as one of the most promising regions for future study, as it is thought to participate in memory and spatial processing.

### 2.2.4 Clinical studies

Clinical studies on patients with unilateral brain damage is usually carried out with the assumption that the observed deficiencies in cognitive functioning after, for example, a localized lesion in the brain, will provide information with respect to the normal functioning of the area of the lesion (McGlone, 1980).

There is some evidence that subjects with left temporal lobe damage have deficits in the performance of verbal tasks compared to normal subjects and patients having undergone right temporal lobe damage (Frisk and Milner, 1991; Ribbler and Rausch, 1990). There is also evidence that subjects with right hemisphere lesions perform at lower levels than normal controls and subjects with left hemisphere lesions when performing a visual-spatial task (Ditunno and Mann, 1990; Warrington and James, 1967). There is, however, evidence from clinical studies indicating that the left hemisphere is also important for spatial processing.

A clinical study, by Mehta, Newcombe and Damasio (1987), found that the subject group with unilateral left hemisphere lesions (25 males) had lower mean scores than the subject group with unilateral right hemisphere lesions (20 males), on a mental rotation task (similar to Vandenberg and Kuse, 1978) and a line orientation task (Benton, Varney and Hamsher, 1978) (similar to the ones to be described in this thesis), and from this they concluded that "the present
findings indicate a substantial left hemisphere contribution to visuospatial processing" (p.458).

A similar study by Mehta and Newcombe (1991), which included the same tasks and also additional related ones, produced evidence supporting the findings of their previous study (Mehta, Newcombe and Damasio, 1987), that there is an important LH involvement in spatial processing. In their study fifty men with unilateral, post-Rolandic injuries were asked to perform five spatial tasks. Twenty-five of the men had left hemisphere lesions, whilst the other twenty five men had right hemisphere lesions. A control group of thirty two male subjects was also used. In a line orientation task the left hemisphere lesion group performed significantly worse than the control group, whereas the right hemisphere lesion group did not perform significantly differently to the control group, though they did perform more poorly than the control group. Also, in a three-dimensional shape rotation task using the same types of shapes as described in Vandenberg and Kuse (1978), except that the subject only had to compare two objects, the scores of the left hemisphere lesion group, and not the right hemisphere lesion group, were significantly inferior to the control group. They suggested that these findings "cast doubt on the conventional (and loosely defined) notion that the right hemisphere is 'dominant' for visuospatial processing" (p.163).

Farali and Hammond (1988) report that in a study on a patient with a large right middle cerebral artery stroke the patient failed "three different mental rotation tasks" but was "able to recognize misoriented numbers, letters, and drawings" (p.20). Other neurological studies supporting a right hemisphere specialisation for mental rotation have also been reported (e.g. Corballis and Sergent, 1988; Ratcliff, 1979).

Another study on visuospatial dysfunction following unilateral brain damage indicated that "LHD (left-hemisphere-damage) disrupts processing of forms at lower levels of hierarchical structure, whereas RHD (right-hemisphere-damage) impairs processing of forms at higher levels" (Delis, Kiefner and Fridlund, 1988, p.427).

In her review, McGlone (1980) summarized her section on clinical studies by suggesting that "the adult clinical literature on verbal and nonverbal functions offers support for the hypothesis that functional brain asymmetry is less marked in the female than the male population" (p.219). McGlone and Kertz (1973) found evidence suggesting that the right hemisphere in males may be more specialized
for spatial processes than for the right hemisphere in females. Support was also found for the suggestion that "women make more use of verbal mediation in traditionally designated nonverbal tasks than do males" (p.320).

Cognitive studies have found "that the effect of unilateral brain damage is less specific in women than it is in men" (Inglis et al., 1982, p.271; see also Inglis et al., 1983; McGlone, 1978). Further support for the above claims was also obtained by a meta-analysis, where sex differences were examined in the effects of unilateral brain damage on intelligence test results (Inglis and Lawson, 1982). In this meta-analysis the Wechsler IQs of 16 studies were examined by means of a linear regression analysis. In another review of previous studies, similar conclusions were also arrived by Inglis and Lawson (1981) who proposed that "a sexual dimorphism in the functional asymmetry of the damaged human brain is reflected in a test-specific laterality effect in male but not in female patients" (p.693).

In a more recent review Snow, Freedman and Ford (1986) were not able to agree with Inglis and Lawson (1981), and suggested that "the generality of a sex difference in the effects of lateralized brain damage is questionable" (p.186; see also Snow and Sheese, 1985).

In a study of aphasics by Friedland and Kershner (1986), support was found for the hypothesis that "males compared to females tend to rely more on the right hemisphere for spatial functions and more on the left hemisphere for language functions; while females are more inclined to use the processing resources of the same hemisphere (in this case the left) to carry out both linguistic and spatial functions" (p.415).

In her review, Halpern (1986) cited evidence that there are sex differences in the recovery of cognitive functions following unilateral brain damage, with males being more affected than females when performing tasks specifically aimed at engaging the damaged hemisphere.

In response to McGlone's (1980) review, Hier and Kaplan (1980) stated that "although there is some suggestive evidence that language deficits may be more profound in males after left-hemisphere injury, further studies are needed to elaborate sex differences in the prevalence, severity, and persistence of aphasia in children and adults. With respect to nonverbal cognitive deficits after right-hemisphere damage, no consistent pattern of sex differences has yet emerged" (p.239). In his review, Harris (1978) cited evidence that spatial and verbal ability
is more unilaterally represented in the right and left hemispheres respectively in males than in females, although she also cited clinical evidence to the contrary.

2.2.5 Cerebral blood flow

Regional cerebral blood flow (rCBF) is another method of measuring hemispheric activation, and is used in the study of hemispheric asymmetry of function (Gur and Reivich, 1980). The non-invasive xenon-133 inhalation technique is a common method of measuring the flow of blood to the cerebral hemispheres. This technique involves mixing tracer amounts of the isotope with air, and then having the subject inhale the gaseous mixture through a face mask. The clearance of xenon-133 from the brain is measured by placing scintillation detectors over regions of the brain, for example, the precentral and parietal regions (Obrist, 1975). This method assumes that there is a correlation between blood flow to the brain and cognitive activity, specifically, that cognitive activity gives rise to an increase in blood flow to the brain (Gur and Reivich, 1980). "During a test involving a specific type of cerebral function there is a local change in nerve-cell activity and hence in metabolic rate that gives rise to an increase in blood flow in the active region" (Lassen, Ingvar and Skinhoj, 1978, p.53). Although there is an association between metabolism and flow, it does not necessarily prove "one (metabolism) to be the determinant of the other (flow)" (Lou, Edvinsson and MacKenzie, 1987, p.292). Lou, Edvinsson and MacKenzie (1987) have suggested that neurons "could, in principle, constitute the coupling mechanism between metabolism and flow" (p.293). There is also an invasive xenon-133 technique, which involves injecting the xenon-133 isotope directly into the carotid artery (Lassen, Ingvar and Skinhoj, 1978).

Gur and Reivich (1975), in a study using the xenon-133 inhalation method, found "a significant increase in left relative to right hemispheric flow during the performance of the verbal task compared to the baseline flow" (p.86), but no significant right relative to left hemispheric flow during the performance of the visual-spatial task. A rank-order correlation was computed between "the amount of increase in the laterality index during the performance of the spatial task and performance on the spatial task" (p.86). This gave a significant correlation between the increase in blood flow to the right hemisphere and better performance. On the other hand, no significant correlation was found between left hemispheric flow and better performance on the verbal task.
An rCBF study by Deutsch et al. (1988), using a mental rotation task (Shepard and Metzler, 1971), found greater right hemisphere blood flow (with respect to the left hemisphere) for both the mental rotation task and a line orientation task. The most robust regional asymmetry observed was a right frontal activation, which they suggested may be due to the general attentional demands associated with most visuospatial tasks. Deutsch et al. (1988) found asymmetries in hemispheric flow favouring the right side in two out of three visual-spatial tasks (mental rotation and line orientation task). However, a fragment puzzle task did not show a significant difference in the activation of the right hemisphere relative to the left, and the investigators suggested that this could be caused by subjects using verbal strategies in the organization of the fragments used in the task. In this study, Deutsch et al. found that women performed worse than men, when performing visual-spatial tasks, especially in mental rotation. They did not, however, find "significant sex differences in the hemispheric pattern of activation" (p.449) using the xenon-133 inhalation technique, although they reported a significantly greater global overall flow in women than in men. They concluded that "there is therefore little evidence provided by rCBF activation that women depend on the right hemisphere less than men with respect to visuospatial processing" (p.449), but noted that "if anything, the extent of asymmetric activation seems greater in women" (p.449) and suggested that this reflected "a greater effort on their part in performing these tasks" (p.449).

Knopman et al. (1980) found an increase in rCBF "at the left posterior-superior temporal probe site with both verbal and nonverbal tasks" (p.109). On the other hand, a study by Risberg et al. (1975) "concluded from the present results that the functional level in the left hemisphere is higher than in the right hemisphere during verbal mental activity and vice versa for spatial activity" (p.521).

In their study using rCBF Papanicolaou et al. (1987) found a significantly greater activation of the right parietal region during a mental rotation task. Deutsch et al. (1987) found a significant difference in rCBF in the frontal regions, with flow greater in the right hemisphere than the left, for both verbal and visuospatial tasks (including a mental rotation, line orientation and puzzles task), particularly the more demanding tasks. They suggested that this "right frontal activation may be due to general attentional demands, associated with many tasks and not limited to tasks thought to involve the right hemisphere" (p.27).
In their study, Gur et al (1982) found that cognitive activity resulted in increased flow of blood to the cerebral hemispheres, with flow greater in the right hemisphere during the performance of the visual-spatial task (line orientation) and "greater in the left hemisphere during the performance of the verbal task" (p.660). Right handed females "showed a stronger lateralization of cerebral blood flow than the right-handed males" (ibid p.660). Females were found to have "a higher rate of blood flow per unit weight of brain" and left handers and females were found to have "a greater percentage of fast-clearing tissue, presumably gray matter" (ibid p.659). The investigators speculated that possibly "a lesser degree of hemispheric cognitive specialization in females is compensated for by greater activation of the hemisphere specialized for a particular task" (p.660).

In a review of gender differences in rCBF, Gur and Gur (1990) found that "only a few studies have examined gender differences in rCBF" (p.248). They noted that most studies of gender differences using the xenon-133 inhalation method found higher overall flows in women than in men, and that these gender differences declined with aging.

2.2.6 Hormonal influences

Males and females differ in their relative concentrations of progesterone, estrogen and testosterone. The most abundant and influential male sex hormone is the androgen testosterone, which is formed and secreted by the interstitial cells of Leydig in the testes. Other androgens include dihydrotestosterone and androstenedione. The female sex hormones include estrogen and progesterone. The estrogens are secreted mostly by the ovaries, but minute amounts are also secreted by the adrenal cortices. Progesterone is only secreted in significant amounts by the corpus luteum during the second half of each ovarian cycle, although the ovaries and adrenal cortices secrete minute amounts during the first half of the ovarian cycle (Guyton, 1986).

The XX female and XY male sex chromosomes primarily determine whether the fetus will develop ovaries or testes respectively. It is the secretion of male hormones by the fetal testes that is responsible for the development of the male sex characteristics, whilst the absence of male hormones will result in the development of female sexual organs. Since sex hormones play a vital role in the development of sexual characteristics in the fetus, it has been speculated that the sex hormones may also influence the "sexual differentiation of the developing
brain" (Halpern, 1986, p.92). From her review on this subject, which included looking at prenatal sex hormone abnormalities such as fetal androgenization, androgen insensitivity and Turner's syndrome, Halpern (1986) concluded that "taken together, research on the influence of prenatal sex hormones on cognitive abilities has not yet provided any definite answers" (p.97). In another review, specifically dealing with prenatal sex hormones and the developing brain, Ehrhardt and Meyer-Bahlburg (1979) concluded that "concerning the effects of prenatal sex hormones on general intelligence or on sex differences in mental abilities, the available data are inconclusive" (p.428).

In their review dealing with prenatal influences on cognitive abilities, Reinisch, Gandelman and Spiegel (1979) were only able to draw some tentative conclusions from the then "available data relating to cognitive ability and performance in both genetic and endocrine syndromes as well as in exogenously exposed individuals" (p.232). Amongst these was the evidence that "prenatal exposure to excess estrogen or to no hormones at all may have a negative influence on the development of spatial-perceptual skills but not on an overall measure of intelligence such as IQ" (p.233), and that in some individuals the excess or absence of sex chromosomes may effect cognitive abilities and measures of general intelligence. For comprehensive reviews dealing with prenatal exposure to hormones and its contributions to sexually dimorphic behavioural development in humans see Reinisch, Ziemba-Davis and Sanders (1991) and Hines (1990).

At puberty, sex hormones are also very important since they influence the development, for both males and females, of secondary sex characteristics. Again, this has led to speculation as to whether sex differences in cognition is a function of maturation rate. For instance, Waber (1976) found that "regardless of sex, early maturing adolescents performed better on tests of verbal than spatial abilities, the late maturing ones showed the opposite pattern" (p.572). This study also found that maturation rate was not related to verbal ability. Waber (1977) stated that "since females mature earlier than males, these data support the thesis that rate of physical maturation is an important determinant of the sex difference in spatial (but not verbal) ability" (p.35). Similar findings in support of Waber's hypothesis have been made by others (Meyer-Bahlburg et al, 1985; Hassler, 1991). However, other studies have failed to support Waber's hypothesis (Rovet, 1983).

In a study involving 13 females with a history of precocious adrenarche (PA), Nass et al (1990) found that PA had no effect on verbal fluency, but "the
spatial abilities of females with a history of PA, who had reached gonarche (were fully pubertal), were inferior to those of females tested in the midst of PA and to population controls" (p.59). The authors suggested that physiological hormonal changes with normal adrenarche prevent the right hemisphere from further specialization, and furthermore that since females usually reach adrenarche before males, they will generally show a relative spatial deficit, with the spatial performance in females with PA being an exaggerated deficit.

In her review, Halpern (1986) stated that "cognitive differences are found more reliably at adolescence" (p.100), but she also suggested that the relationship between sex hormones and cognitive abilities is influenced by other, as yet, unknown variables. She pointed out that hypothesised mechanisms for the effect of sex hormones during puberty upon the development of cognitive abilities, "cannot explain the sex differences that are found in childhood" (p.100). Dan (1979) concluded from her review of "the menstrual cycle and sex-related differences in cognitive variability" that "no changes in cognitive performance have been consistently demonstrated" (p.255).

Hampson (1990a) studied a range of cognitive and motor measures in women during the menses and the preovulatory phase of the female sexual cycle (also called menstrual cycle or ovarian cycle). In the preovulatory phase there is a great increase in the secretion of the estrogen sex hormone estradiol, but not progesterone. During menses both estrogen and progesterone hormone levels are low. This study found poorer performance on tests of spatial ability to be associated with the preovulatory phase, suggesting that variation in the production of estradiol over the female sexual cycle may have an effect on cognitive functioning. Higher levels of estradiol were associated with poorer performance on visual-spatial tasks, which in this study consisted of the rod-and-frame test, hidden figures test, and the space relations test. Other tasks showed the opposite associations with significant enhancement during the preovulation phase observed in an articulatory test and a manual speed test, whereas, a perceptual speed test and a verbal fluency test showed no significant change over the female sexual cycle. Other studies have added support for some of these findings (Hampson and Kimura, 1988; Hampson, 1990b).

A study by Chiarello, McMahon and Schaefer (1989) also found a variation in female performance in different stages of the menstrual cycle. In contradiction to the study by Hampson (1990a), however, they found that the females performed best on a spatial task (line orientation) over the follicular phase.
of the menstrual cycle, when estrogen levels are rising or maximal, and worst during menstruation. There was a significant male advantage in performance in the line orientation task, even when the females were performing at their peak. Female performance was also found to vary in a lexical decision task. The females, during the menstrual phase, when hormone levels were low, showed a pattern of hemispheric performance that differed from males.

In another study, Heister et al (1989) investigated whether hemispheric superiority was dependent on the phase of the female sexual cycle. A left hemisphere advantage for verbal processing was found, but this did not change through the menstrual cycle. A large right hemisphere superiority for face perception was found during menstruation, but this changed to a small left hemispheric superiority during the premenstrual phase. The authors proposed that their evidence of the influence of hormones upon the balance of hemispheric activation was "relevant not only for the discussion of sex differences in cerebral asymmetry but also for the concept of cerebral organization in general" (p.871).

A review on "hormones and cognitive functioning in normal development" by Petersen (1979) found that females who scored higher on spatial tests appeared to be more masculinized (androgynous), but that males who were masculinized performed better in tests at which females excelled. She noted that this result is "difficult to combine with a socialization hypothesis for males, if we assume that those who are more sex-stereotypic in appearance will be more sex stereotypic in performance" (p.205). A meta-analysis by Signorella and Jamison (1986) failed to find any evidence that androgyny was associated with better cognitive performance.

In his review Harris (1978) found evidence suggesting "that there is a relationship between sex hormone level and spatial skill, but it is highly complex and different for males and females" (p.482). McGee (1979) cited some support for the hypothesis that hormonal differences in males and females are to some extent responsible for the sex difference observed in spatial test performances, but left the precise nature of the relationships between hormonal balance and spatial abilities "an open question" (p.906). More data is available now, but consensus has yet to emerge.
2.2.7 Other Modalities

A study (31 males, 35 females) by Bowers and LaBarba (1988), using the dual-task paradigm, found sex differences in the lateralization of spatial abilities. The dual-task paradigm is a relatively new method being used to investigate lateralization patterns, and involves the subject doing two tasks at once. In this experiment the subjects tapped a telegraph key while at the same time performing a spatial visualization (SV) task or spatial orientation (SO) task. A right hemisphere pattern of control for the SV component was found, regardless of sex and ability level. In processing SO, high ability males and females displayed a left hemisphere lateralization, whereas low ability males and females displayed a right hemisphere control. Also observed was that high ability females and low ability males may use a verbal strategy in processing SV tasks, but no such verbal mediation effects were found for the SO component.

2.2.8 Cerebral processing of mental rotation

Sliepand and Metzler (1971) found that the time required to perform mental rotation of three-dimensional objects, when comparing two objects, was "(i) a linearly increasing function of the angular difference in the portrayed orientations of the two objects and (ii) no shorter for differences corresponding simply to a rigid rotation of one of the two-dimensional drawings in its own picture plane than for differences corresponding to a rotation of the three-dimensional object in depth" (p.701).

Arguments have been put forth that mental rotation is an analog operation (Shepard, 1982), but others have argued against the analog approach, in favour of the propositional or "tacit knowledge account" (Pylyshyn, 1979; Pylyshyn, 1981). In a review of studies on mental rotation Corballis (1982) suggested a "way to partially reconcile analogue and propositional accounts of imagery is to suppose that images are stored in propositional fashion but displayed in analogue format" (p. 195).

There is evidence suggesting that the right and left hemispheres, at least to some degree, process visual-spatial information differentially: In a study involving unilateral brain damaged subjects, Mehta and Newcombe (1991) found evidence implicating both hemispheres in shape discrimination when Euclidean geometry was involved. The shapes being matched were similar to the MRT
objects used in this experiment. Results of their study also suggested that the LH engages in processes involved in rotation itself, which "tap into imagery resources, specifically those essential for the regeneration of images of the stimuli as they are mentally rotated" (p.165). Their study also suggested that the intervention of the LH is "necessary to suppress distracting visuospatial material" (ibid, p.165).

Concerning "shift" transformations, Kosslyn (1987) made some predictions about the role of the two hemispheres. He stated firstly that "the repositioning operation performed by the position-alteration subsystem depends on altering the topographic representation of the layout of individual parts" (p.166). He then suggested that the processing subsystem producing this coordinate representation is more effective in the RH. Kosslyn then argued for a RH dominant realign subsystem, where categorical representations are used to realign the parts of a complex figure. The representations used by the realign subsystem were, however, suggested to be more effectively encoded in the LH. In the above theory, both hemispheres would be expected to be involved in the process of "shift" transformation of complex shapes, such as those used in a complex mental rotation task.

Farah (1989), in a review on the neuropsychology of mental imagery, found growing evidence that the process of generating images was dependent upon an area in the posterior left hemisphere, and that once generated, mental imagery consisted of activity in the visual cortex proper, which included visual association areas in the temporal and parietal cortex. She also suggested "that mental image rotation depends upon parietal cortex, with some degree of right hemisphere superiority for this process" (Farah, 1989, p.410; see also Farah, 1984; Farah et al, 1985).

It has been suggested that mental rotation may elicit a more analytic processing strategy, which may be more of a LH capacity than a RH capacity, and vice versa, that other more simple visual-spatial tasks may elicit a more synthetic processing strategy, which may be more of a RH capacity than a LH capacity (Ornstein et al, 1980).

Also, it has been speculated that the process of mental rotation may be more efficient when the LH is "engaged in holding information in working memory, releasing right-hemispheric mechanisms for mental rotation" (Corballis and Sidey, 1993, p.196). In their study Corballis and Sidey reported that "concurrent memory load appeared to increase mental-rotation rate of letters in
the RVF relative to those in the LVF" (ibid p.195). In a previous experiment, where visual field differences were not examined, Corballis (1986) found the contrary, where memory load did not appreciably effect the mental rotation rate.

Carlton (1988) used the mathematical notion of a group acting on a function space as a way of linking "perceived mental rotations of a three dimensional object (Shepard and Cooper, 1982) with the sequence of internal activities in the visual cortex, that is, a link between a path in geometrical space to a path in brain state space" (Soto-Andrade and Varela, 1991, p.221). Carlton's construction was argued by Soto-Andrade and Varela (1991) to be biologically restrictive and unable to be completed in the desired way.

2.3 ELECTROPHYSIOLOGICA CORRELATES OF VISUALSPATIAL FUNCTION

Electrophysiological studies usually involve the measurement and analysis of electroencephalogram (EEG) signals or event related potentials (ERPs), monitored during the performance of cognitive tasks, including verbal and visual-spatial tasks, with the differential electrical activity recorded thought to be indicative of cognitive activity (Ray et al, 1981). For a review dealing with asymmetry of electrophysiological phenomena and its relation to behaviour in humans see Marsh (1978).

This core detailed literature review on electrophysiological correlates of visual-spatial function is divided into two main parts. The first part deals with the ongoing EEG and the second part deals with ERPs.

2.3.1 Ongoing Electroencephalogram (EEG)

Electrical recordings from the scalp measure the continuous electrical activity of the cortex. The intensity and patterns of the electrical activity is to a great extent determined by the excitation level of the neurons in the superficial layers of the cerebral cortex (Chusid, 1982). The entire record of the recorded electrical potentials is called an electroencephalogram (EEG).

The spatial resolution of the spontaneous EEG is determined by the electrode density, and the temporal resolution by the sampling rate. Interpretation of the spontaneous EEG is not always straightforward, due to the different kinds of artifact contaminating the signal (Barlow, 1986), or the type of information
needed from the EEG signal. Most continuous EEG data is subjected to further analysis to extract more useful information, for example, estimation of the power in the delta, theta, alpha and beta bands by means of spectral analysis (Davidson et al, 1990). This results in a loss of temporal resolution, as time period epochs are subjected to spectral analysis using the Fast Fourier Transform (FFT). The Fourier integral period (epoch) determines the resolution of the FFT which is limited inversely by the duration of the epoch (Kahn et al, 1988).

Hans Berger was the first person to report on the EEG phenomenon associated with cognition when he observed that there was a decrease in the amplitude of the alpha rhythm during mental arithmetic (Berger, 1929). In traditional EEG studies, alpha activity is observed "under the assumption that the presence of alpha denotes cortical deactivation and thus a lack of cognitive processing" (Ray et al, 1981, p.719). Suppression of the alpha rhythm is thought to "reflect the withdrawal of neurons from the pool of synchronised cortical units" (Butler, 1980, p.232). It has been suggested that there will be less alpha appearing in the left hemisphere during verbal tasks, and that there will be less alpha appearing in the right hemisphere during visual-spatial tasks (Rebert and Mahoney, 1978; Furst, 1976).

Galin and Ornstein (1972) studied EEG asymmetry in 10 right-handed subjects (5 males, 5 females) using bilateral EEG recordings from the parietal and temporal regions. The ratios of average power (1-35 Hz) was then computed, and the right hemisphere over left hemisphere ratio was found to be greater in the verbal tasks than in the spatial tasks. The spatial tasks were the Modified Kohs block design, and the Modified Minnesota Paper Form Board test. The verbal tasks involved mentally composing a letter and writing a letter. The finding by Galin and Ornstein (1972), that the pattern of EEG asymmetry reflected a differential engagement of the hemispheres in the performance of spatial and verbal cognitive tasks, provided a foundation that future studies such as Doyle, Ornstein and Galin (1974) built upon, especially with the use of discrete Fourier transforms in the analysis.

It was found by Doyle, Ornstein and Galin (1974) that the right/left ratios of hemispheric power in the alpha band, and to a lesser degree of consistency in the beta and theta bands, was significantly higher in verbal and arithmetic tasks than in spatial tasks. EEG recordings were made bilaterally from the parietal and temporal regions in 10 right-handed adults. The spatial tasks used included the
Modified Kohs Block Design and the Modified Minnesota Paper Form Board test, both of which had been used in the study by Galin and Ornstein (1972).

An EEG study by Dumas and Morgan (1975) found no such differences on the basis of difficulty or occupation, but found significant results when looking at task laterality. The visuospatial task was the Nebes’ ring test. A facial memory test was also used as a "right hemisphere task". A linguistic task and mathematical task were used as "left hemisphere tasks". The 17 right-handed subjects consisted of 9 male artists and 8 male engineers, with EEG alpha recorded bilaterally from the occipital regions. It was found that there was alpha suppression in the hemisphere dominant for a particular task relative to the total amount of alpha. Hence, the right hemisphere tasks (Nebes' rings and faces) were found to show alpha suppression in the right hemisphere relative to the total amount of alpha. The finding of no difference in the asymmetry of occipital alpha as a function of occupation has been attributed by Furst (1976) to the use of the wrong criterion variable for cognitive ability, and Furst argued that subjects should be selected on basis of visuospatial ability rather than occupation.

A study by Galin and Ellis (1975), using 6 right-handed adults as subjects, involved the recording of flashed (task irrelevant) evoked potentials (see Section 2.3.2) and background EEG from the right and left parietal and temporal areas while the subjects engaged in spatial and verbal tasks. It was found that the overall power and peak amplitude characteristics of evoked potential asymmetry, together with the concomitant asymmetry in EEG alpha power, both reflected the expected hemispheric specialization for the cognitive tasks, with the latter being more consistent. The spatial task was the Modified Kohs Block Design, and in all leads and subjects the alpha power ratio (right/left) was lower in this task then in the Write-from-Memory task.

A study by Furst (1976), examining EEG alpha asymmetry and visuospatial performance, found that subjects (16 right-handed males) showing relatively less right hemisphere alpha activity, implying relatively greater right hemisphere activation, performed better on the visuospatial tasks. The tasks consisted of the subjects solving problems involving the imaginary manipulation of visually presented objects. The three visuospatial problems were cube folding, three-dimensional rotation (Shepard and Metzler, 1971), and paper folding. The study by Furst (1976) used students selected for high spatial ability, with EEGs recorded from two electrodes, placed in the occipito/parietal site of each hemisphere.
An EEG study utilizing 39 right-handed subjects (20 males, 19 females) by Tucker (1976) indicated right hemisphere specialization for males in a synthetic visuospatial task, where irregular, apparently meaningless shapes, had to be synthesized into an integrated Gestalt of a face. However, when perceptual analysis was required during the performance of a Gottschaldt embedded figures test, it was found that the left hemisphere became important in the visuospatial processing as well. Also, "under the assumption that greater alpha desynchrony indicates greater cortical processing" (p.450), it was found that females used their posterior, especially occipital, regions significantly more than males on the Gottschaldt embedded figures test and the Wechsler Adult Intelligence Scale vocabulary subtest. The EEG signals were recorded from the left and right temporal, parietal, and occipital sites in the ten-twenty system.

A study by Rebert and Low (1978) examined EEG alpha asymmetry in bilateral EEGs recorded from 14 subjects (7 males, 7 females) from electrodes placed in the temporal, central and parietal regions. The subjects were tested under 6 different task conditions, including the performance of a mental rotation task similar to that of Shepard and Metzler (1971). The results indicated greater activation in both temporal regions during language processing (reading to subject) than the parietal regions, but greater activation in both parietal regions during the performance of the visuospatial mental rotation task. Overall, the alpha power was reported to be greater in the left hemisphere relative to the right hemisphere during mental rotation, whereas a reverse pattern of asymmetry was found for the verbal task. Moreover, when subjects were engaged in either watching or playing "Pong" (TV tennis), alpha power was suppressed in the right hemisphere when compared to inter-game rest periods. Gender was mentioned as being one of a number of factors and interactions being significant, but the details were not discussed.

A study by Galin, Johnstone and Herron (1978) used block designs as a spatial task, and writing from memory as one of the verbal tasks. The EEG was recorded bilaterally from electrodes placed in the central and parietal areas, with 16 right handed subjects (8 males, 8 females) used in the study. It was found that the right/left alpha ratios were significantly lower for block design than for writing, regardless of the degree of difficulty in the block design. There were, however, some important individual differences found when correlating alpha power with the difficulty of the block design. It was found that all significant correlations showed an increase in alpha power as difficulty of the block design
increased. Some subjects showed significant alpha power increases only in the right hemisphere, which was interpreted as a shift towards a verbally mediated mode of problem solving, and some subjects showed significant alpha power increases only in the left hemisphere, which was interpreted as an inhibition of verbal processes. Other subjects showed significant alpha power increases in both hemispheres, a finding that was difficult to interpret.

Trotman and Hammond (1979), in an EEG study designed to investigate whether task-related asymmetries in alpha rhythm suppression showed sex differences, studied 10 right-handed subjects (5 males, 5 females). The investigators found that in verbal-numeric and visuo-spatial tasks, the proportion of right hemisphere alpha activity was different between the tasks in males, but not in females. Whilst the female group showed no difference, the male group showed "relatively less left hemispheric alpha under the verbal-numeric conditions and relatively less right hemispheric alpha under the visuo-spatial conditions" (p.430). The visuospatial tasks employed visual imagery, two of them involving the rotation of a coin or a cardboard box, whereas in the third visuospatial task the subjects were asked to imagine themselves sitting on the beach watching the waves come in. Trotman and Hammond suggested that their results indicated a more strict segregation of function in males in the degree of lateralization of hemispheric function. EEGs were recorded from electrodes placed over the left and right temporal areas.

A study by Wogan et al (1979), on sex difference and task effects in lateralization of EEG-Alpha, used 11 right-handed subjects (6 males, 5 females), and found that depending on the task, males were more consistently lateralized, whether right or left, compared with females. On Block Designs, The Rod and Frame Test, or Mental Letter, males apparently adopted more consistent processing strategies, whereas females failed to show consistent lateralization across replication. For males the Mental Letter was lateralized to the left, the Block Design to the right and the Rod and Frame Test to the right. The findings in relation to the Block Design task and Mental Letter task is consistent with other studies (Galin and Ornstein, 1972; Doyle, Ornstein and Galin, 1974; Galin and Ellis, 1975). However, in the Embedded Figures Test the males showed more shifts than females in lateralization across replications. Wogan et al's suggested that "some complex tasks like the Embedded Figures Test may call on simultaneous processing from both hemispheres" (p.222). EEGs were recorded from electrodes placed in the left and right temporal areas.
In a study on verbal and spatial tasks Gevins et al (1979) found "no support for the idea that lateralized EEG differences in different tasks reflect cognitive processes" (F.667). They analyzed the EEGs during the performance of the tasks using two-stage, nonlinear multivariate pattern recognition. Two experiments were carried out using right-handed subjects. In experiment 1, using 23 adults (18 males, 5 females), Koh's block design and mental paper folding were used as spatial tasks, whilst reading and writing from memory were used as verbal-logical tasks. In experiment 2, 32 adults (23 males, 9 females) were used, and one of the several tasks performed by the subjects involved the mental rotation of block structures, this being a spatial task similar to that of Shepard and Metzler (1971). Gevins et al suggested that their study indicated the involvement of large, bilateral areas of cerebral cortex in the performance of complex higher cortical functions. They attributed any lateralized EEG differences between different tasks as most likely due to "intertask differences in efferent activities, stimulus characteristics, or performance-related factors, rather than to cognitive differences" (p. 667). The efferent activities mentioned are limb and eye movements, and the performance-related factors mentioned are task demands and the subject's ability and effort. Gevins et al noted that these non-cognitive factors have not been adequately controlled for in previous experiments (among those cited were Galin and Ornstein, 1972; Dumas and Morgan, 1975; Doyle, Ornstein and Galin, 1974; Galin, Johnstone and Herron, 1978). Bilateral EEG recordings were made from a total of eight electrodes, situated in the occipital, parietal, central and frontal regions. Although there were no lateralization effects, Gevins et al did find a reduction of approximately 10 per cent in the magnitude of the alpha and beta band spectral intensity for mental rotation, as well as other tasks, when compared to a visual fixation task. This reduction was reported to be approximately the same over the occipital, parietal and central regions, with minor differences in the beta band over the frontal region. Gender effects were not discussed.

In a study using 20 subjects (10 males, 10 females), where alpha power from EEG recorded from parietal and central areas bilaterally, Ornstein et al (1980) found that five out of six spatial tasks appeared to engage the right hemisphere more than the single verbal task. Complex mental rotation was found to have a similar EEG pattern to the verbal task. Their findings were interpreted as being consistent with the hypothesis that mental rotation "primarily engages the left hemisphere" (p.59). A modified version of Shepard's mental rotation task was
used, similar to that used by Vandenberg and Kuse (1978). The other spatial tasks used were Nebes Arc-Circle, Circle-Circle Matching, Modified Minnesota Paper Form Board test, Paper Completion and Facial Recognition. The verbal task used was a verbal-analytic definitions task. It was also found that the whole-whole portion of Nebes's (Circle-Circle) test engaged the right hemisphere more when compared to the Nebes's part-whole (Arc-Circle) test. Greater task dependent asymmetry was reported in the parietal areas than in the central areas between the verbal task and the six spatial tasks. Ornstein et al stated that the critique by Gevins et al (1979) of EEG alpha asymmetry work was heavily based on the expected, but apparently wrong assumption, that mental rotation is a right hemisphere task. Also, with respect to Gevins et al (1979) claim that a most of the EEG alpha asymmetry findings were due to task differences in afferent and efferent activity, Ornstein et al (1980) noted that they controlled for these factors and still found task dependent alpha asymmetry. There appeared to be no significant gender effects.

In an EEG study (62 males, 48 females) using a paper folding visuospatial task, Ray et al (1981) found that for high spatial ability males there was a correlation between EEG asymmetries and task performance similar to that of Furst (1976), where greater right hemisphere activation was associated with better spatial problem solving. The low spatial ability males showed the opposite effect, where more left hemisphere functioning was associated with better spatial performance. Ray et al suggested that perhaps a verbal or analytic strategy is associated with successful spatial problem solving in males with low spatial abilities. The females showed no marked relationship between lateralization and cognitive performance. The relationship between the timing of puberty and EEG asymmetry during the spatial visualization problems, which was investigated in the women, showed no significant association. Two electrodes were used, placed in the left and right parietal areas.

Osaka (1984) investigated the effect of task difficulty on the alpha wave by bilaterally recording EEGs from the frontal and occipital regions in 10 right-handed subjects (5 males, 5 females) while performing two visuospatial tasks and two arithmetic tasks. The visuospatial tasks were visual imagery, involving the recall of a three-dimensional figure and then drawing it, and mental rotation, where the figure had to be rotated mentally and then drawn. In both visuospatial tasks the figures used were similar to that of Shepard and Metzler (1971). It was found that the peak alpha frequency of the power spectrum, for both the
visuospatial and arithmetic tasks, increased significantly above the peak alpha frequency recorded in the resting level condition, and that the shift towards higher frequency within the alpha band increased as the task difficulty increased. It was also found that for the more difficult arithmetic task and the more difficult visuospatial task (mental rotation), the hemispheric asymmetry in the peak alpha frequency was larger than for the easier tasks, with an increase in the peak alpha frequency in the right rather than left hemisphere in the visuospatial tasks, and vice-versa for the arithmetic tasks. A task difficulty effect on the alpha power was also found to be significant, where the alpha power decreased during the performance of the tasks when compared with the rest period. However, no significant difference was found for the alpha power among the tasks. The observed absence of lateralization was attributed to the large decrease in alpha power caused by the "difficulty effect". Gender effects were not discussed.

A study by Ray and Cole (1985) indicated potential problems with the use of alpha activity as an index of cognitive activity, as they found that differential attentional demands may have been a confounding factor in the results. Two experiments were performed, but only the first experiment involved the use of visuospatial tasks, with 18 right-handed subjects (9 males, 9 females) having the EEG recorded bilaterally from the frontal and parietal regions. The spatial tasks included a paper folding task, the Mooney facial closure task, mental rotation of a geometric figure, and the visualization of an imaginary walk. From this study the investigators suggested that EEG beta may be useful in indexing appropriate cognitive processes. Differential hemispheric activation for beta was found most strongly in the parietal areas for the visuospatial and verbal tasks, with a greater difference in beta activity between the hemispheres observed for the verbal tasks than for the spatial tasks. Both experiments controlled for attentional and motor requirements, and no differences in alpha activity appeared to be associated with cognitive processes.

In a study on power suppression and asymmetric hemispheric activation during verbal and spatial cognitive tasks, using 19 right-handed females as subjects, Davidson et al (1990) showed some differential activation of the left and right hemispheres. The EEG was recorded bilaterally from electrodes placed in the frontal, parietal and central regions. The spatial task (dot localization) was found to show greater activation in the right hemisphere, and greater relative power suppression in the right hemisphere was associated with better performance on the spatial task in the vertex-referenced data, but this association was not
significant. With the verbal task (word finding), which showed greater activation in the left hemisphere, greater relative left hemisphere activation was associated with better performance in the vertex-referenced data. Correlations using averaged-ears referenced data was considerably weaker. There were significant task by hemisphere effects in the alpha and beta bands for both vertex and ears-referenced data. These effects were interpreted as being due to "either greater power suppression in the hemisphere putatively most engaged in task processing or greater power in opposite hemisphere" (p.528).

2.3.2 Event Related Potentials (ERPs)

"ERPs consist of a series of transient perturbations of the spontaneous EEG, time-locked to some externally definable event such as the onset of a stimulus" (Rugg and Barrett, 1987, p.338). The term ERP is used interchangeably with the term evoked potential (EP). ERP studies involve recording the EEG from scalp electrodes whilst the subject is engaged in a task, such as the presentation of a tachistoscopically presented item. It is suggested that large ERP responses (the amplitude of the ERP) "reflect greater resource allocation or processing" (Nelson, Collins and Torres, 1990, p.96), so that a hemisphere which is dominant for a certain ability, when presented with stimuli involving the use of that ability, will yield larger late components than if the same stimuli was presented to the non-dominant hemisphere. Hence, "subjects should produce left-hemisphere ERP responses that are larger to language than to non-language stimuli presented in the right visual field" (p.96).

Transient ERPs can offer millisecond resolution of short lasting events but cannot follow changes in the ERP which occur during the averaging period. Usually, up to hundreds of responses may be averaged in order to achieve a satisfactory signal to noise ratio of the smaller components, so only those processes which are time invariant over the recording period are able to be studied (Silberstein et al, 1990; McGillem and Aunon, 1987).

If the stimulus for the ERP is irrelevant to the task then the "amplitude of the evoked potential increases as a function of the background EEG alpha" (Galin and Ellis, 1975, p.49). Increasing attention or involvement is "usually associated with decreasing background EEG alpha" (p.49), and therefore a decrease in amplitude of the late components in the task irrelevant EPs may be predicted as a
result of increased cognitive processing (involvement) of a task in the cortical regions involved in the cerebral processing of the task.

The procedure used by Galin and Ellis (1975), involving the task irrelevant flashed EPs, is a technique that has become known as probe EPs. Shucard, Sliucard and Thomas (1977) reported that they had used auditory evoked potentials as probes of hemispheric differences in cognitive processing. The clear exposition of the assumptions underlying the probe EP method, as well as an outline of many of its possible uses, was first articulated by Papanicolaou (1977-as cited by Papanicolaou and Johnstone, 1984). Hemispheric activation may be interpreted as probe EP attenuation, where "it would be expected that differential regional engagement in a given task will result in attenuation of at least some probe EP components over the regions engaged in the task" (Papanicolaou and Johnstone, 1984, p.118). For example, greater right hemisphere attenuation relative to the left hemisphere, due to increased cerebral processing of information in the right hemisphere relative to the left hemisphere, may be consistent with right hemisphere dominance for some visuospatial tasks. See Papanicolaou and Johnstone (1984) for a comprehensive review of probe EPs, with regard to theory, method and applications. In this review, studies using task irrelevant stimuli will be indicated as such.

A study, designed to test the findings of Galin and Ellis (1975), was performed by Mayes and Beaumont (1977), using 13 right-handed subjects. EPs (task irrelevant flash stimuli) were recorded from O1-P3 and O1-P4. The spatial motor task (Kohs blocks task) and verbal motor task (writing from memory) were identical to Galin and Ellis (1975). An additional spatial task involved mentally reordering blocks to a specific remembered design, whilst an additional verbal task involved mentally composing a statement. No convincing EP asymmetry was found during any of the task conditions, in contrast to the finding of EP asymmetry reported by Galin and Ellis (1975). However, task differences in probe EPs were found across both hemispheres. The spatial motor task yielded smaller responses in the N1 and P2 components of the EP when compared with the verbal motor condition. The experiment by Mayes and Beaumont (1977) has been evaluated by others as not being a replication of the Galin and Ellis (1975) experiment, as recording procedures and dependent measures were not comparable (see Papanicolaou and Johnstone, 1984).

A study by Beaumont and Mayes (1977), using 20 right-handed subjects (10 males, 10 females), investigated whether task and sex differences influenced
the visual EP (task irrelevant flash as evoked stimuli). Electrodes were placed bilaterally at central and parietal sites. The investigators found no convincing task by hemisphere interactions, but found that females showed greater amplitude of the N2 component, at a parietal and a central site, for both hemispheres and for both spatial and verbal mental tasks. Both tasks involved the use of a nursery rhyme familiar to the subject. In the spatial condition, the letters in the rhyme had to be classified as containing a curve or not, when imagined in uppercase form. There were also sex differences on the late components P6 and N6, indicating that concurrent spatial thinking resulted in the visual EPs of females becoming positive relative to those of the males, especially in the right hemisphere, consistent with the hypothesis that females show differential hemisphere involvement in spatial tasks. In their review, Papanicolaou and Johnstone (1984) noted that the complex tasks used by Beaumont and Mayes (1977) may not be expected to elicit differential hemispheric engagement.

One of several experiments by Stuss et al (1983) looked at ERPs during mental rotation. Eight right-handed male subjects were used in the experiment, with ERPs recorded from 11 electrodes, placed at positions Cz, Oz, F7, F8, T3, T4, P3, P4, F3, F4 and Pz. The mental rotation task was derived from the spatial relations subtest of Thurstone’s Adult Primary Mental Abilities Test, and consisted of identifying whether two figures were identical or mirror images to one another, when one figure was rotated between 45° to 135° with respect to the other figure in the plane of the stimulus. A naming task was also performed. The investigators reported an Nx-Ny complex, occurring at approximately 250 msec and 420 msec respectively, evident in both tasks. However, with respect to the naming task, there was a large prolonged negativity in both parietal regions with the mental rotation task in the slow waves (slowly varying positive and negative electrical potentials) following the biphasic negative wave. However, this conclusion by Stuss et al that mental rotation is indexed by a late, posterior negativity, has been criticised by Peronnet and Farah (1989), on the basis of using an inappropriate baseline. They also questioned which of the many component cognitive processes involved in the task was reflected, as well as whether the task was a valid mental rotation task.

Instead of a task irrelevant flash, Papanicolaou et al (1983) used a task irrelevant probe tone stimulus, in a study looking at the cerebral activation patterns in an arithmetic and a visuospatial processing task. In the visuospatial task, the subjects had to decide whether the scattered sections would match the
intact form, if integrated. Fourteen right-handed males were used in the experiment, and EPs were recorded bilaterally from electrodes placed in the temporal and parietal regions. It was found that the probe EP amplitude was attenuated in the left temporal and both parietal regions, but especially so in the right parietal region, during performance of the unmatched shapes visuospatial task, whereas the probe EPs were reduced in amplitude only in the left temporal region during performance of the arithmetic task. It was suggested that these results indicated patterns of regional cerebral engagement that were distinct for the two types of cognitive activity. The findings of this study were described as "confirming the widely documented involvement of the left hemisphere in serial-analytic operations and of the right posterior areas in visuospatial processing" (Papanicolaou and Johnstone, 1984, p.122).

The finding of two quite different patterns of ERP activity by Johnson, Cox and Fedio (1987) suggested the possible effect of different strategies used in performing mental rotation tasks. Twelve right-handed subjects (4 males, 8 females) were used, and ERPs were recorded from electrode locations Fz, Cz, Pz, and bilaterally in the frontal, parietal and central regions. The mental rotation task involved mentally rotating the outlines of hands presented in different orientations in order to decide whether the left or right hand was displayed. The parietal maximum negative slow wave reported to occur during mental rotation by Stuss et al (1983) was not evident in any of the subjects used by Johnson, Cox and Fedio. In one group of subjects, the appearance of a second positive wave (P300) was interpreted as suggesting that the subjects in this group used a two stage serial process to identify the stimulus. Another group performed with fewer errors and produced a large frontal-central negative slow wave that began after P2, similar to the parietal maximum negative slow wave reported by Stuss et al (1983), but with a different scalp distribution. It was suggested that this group employed a more effective strategy, perhaps involving the rotation of the visual images without using verbal rules. Laterality effects and gender effects were not mentioned in the study.

A study by Papanicolaou et al (1987) with probe EPs, using a task irrelevant flash as a stimulus, revealed a significantly greater activation of the right parietal region with respect to the left parietal region, during the performance of a mental rotation task (Shepard and Metzler, 1971), when compared to a control task. EPs to strobe flashes from right and left parietal scalp positions were recorded from 19 right-handed subjects (10 males, 9 females). The
asymmetric amplitude reduction in the right hemisphere was most evident in the P200 component. Regional cerebral blood flow (rCBF) was measured simultaneously with the EPs, in order to look at the concordance between the two techniques. The rCBF technique estimates the actual metabolism. The agreement between the probe EP method and the rCBF technique, with both showing increased activation in the right parietal region, was interpreted as validating the assumptions of the probe EP paradigm. This study did not discuss gender effects.

The main purpose in a study by Wilson et al (1989) was to replicate and extend the findings of Papanicolaou et al (1987). In their first experiment they used a task irrelevant flashed checkerboard probe stimulus, and recorded EPs and magnetic evoked fields (EFs) from the left and right occipital regions. Six right-handed males were used as subjects in experiment 1. The visuospatial task used was patterned on the Shepard and Metzler (1971) mental rotation task, which was the same task used by Papanicolaou et al (1987). The EPs showed a bilateral reduction in the N140 amplitudes, whilst there was a greater decrease in the EP P200 amplitude in the right hemisphere relative to the left hemisphere. This was similar to the pattern observed by Papanicolaou et al (1987), except that in this study the electrode positions were in the occipital regions rather than in the parietal regions. The magnetic EF also showed a bilateral reduction in the probe N140 amplitudes, of similar proportions of that of the EP data, suggesting that both measurements were indexing the same underlying neural functions. However, the amplitude reduction of the P200 in the magnetic EF was similar in both hemispheres. Wilson et al suggested that the electrical P200 component reflects neural activity from a number of sources, and that "asymmetrical cortical resource allocation associated with visuo-spatial processing does not occur in the occipital regions" (p.236). It was suggested that the lateralization of function observed in the probe EPs could be due to a more anterior right hemisphere asymmetry in resource allocation. In a second experiment, an auditory probe (600 Hz, 65 dB tone) was used, instead of a visual probe, in 4 right-handed subjects, and EEG signals recorded from electrode sites C3 and C4. No other experimental parameters were changed. No significant difference in the electrical EPs or magnetic EFs between the two control type tasks and the mental rotation task was found.

In an ERP study with a mental rotation task involving letter rotation, Peronnet and Farah (1989) found that the ERP in the mental rotation task showed a late posterior negativity relative to the ERP from a baseline condition. ERPs
were recorded from the midline sites Oz, Pz, and Cz in 12 subjects (sex not mentioned). The investigators also reported a direct relationship between the amount of late posterior negativity and the amount of mental rotation performed by the subject, and in particular they suggested that the latency range 400-800 msec was a good index for mental rotation. From their results they concluded that the mental rotation process engages primarily posterior brain regions. Laterality effects and gender effects were not examined. These findings of Peronnet and Farah have been replicated by Wijers et al (1989).

An ERP study by Wijers et al (1989) combined the classic attention paradigm with memory search and mental rotation. ERPs were recorded from 8 right-handed subjects (4 males, 4 females), with electrodes located at positions Fz, Cz, Pz and Oz. The mental rotation paradigm involved letter rotation, with the subject required to indicate whether a letter was presented normally or in mirror image to a prememorized letter. Four different orientations of the stimulus letters were used. Before performing the mental rotation, the subjects had to attend to stimulus letters in one colour, and then within this colour category the subject had to search for target letters from a memory set. A finding of this study similar to that obtained by Peronnet and Farah (1989) was that a late posterior negativity (in the 350-700 msec range) increased systematically as the angular disparities increased, with this effect appearing to be largest at Pz. The effect of memory load (at Cz) appeared to precede the effect of mental rotation (at Pz), with onsets estimated at 280 msec and 340 msec respectively. Furthermore, an earlier occipital effect of mental rotation was found in the 200-300 msec range, and it was suggested that this was possibly due to pre-attentive character orientation. Laterality effects and gender effects were not examined.

Taylor, Smith and Iron (1990), in a study investigating sex differences in the ERP during the performance of visual recognition tasks, and which involved recurring verbal items and recurring nonverbal figures of a geometric and curvilinear abstract shape, noted that "effects of sex on endogenous ERP components are rarely mentioned" (p.692). This study found significant distributional (anterior-posterior) differences of the ERPs between the sexes. The tasks were memory tasks, but as the figures task was visuospatial, the results of this study are included in this review. The investigators found that all ERP latencies were longer for males than females and that there were "sex by task by electrode interactions in the amplitudes, due to larger ERPs (P2, N4) for females anteriorly for the figures, but slightly larger posteriorly for the verbal task"
A total of 48 subjects (24 males, 24 females) were used in this study, including four left-handed subjects, and ERPs were recorded from 19 scalp electrodes. The subjects did not differ in their reaction times or number of errors in the two tasks. There were, however, no sex by hemisphere interactions. From these results, the investigators suggested that differences in biological mechanisms may be responsible for sex differences in cognitive abilities. They also noted that their results made it more difficult to invoke factors such as social expectations or differences in early experience, as explanations for cognitive sex differences.

A study by Ruchkin et al. (1991), on ERPs during arithmetic and mental rotation, found a number of late posterior negativities which were sensitive, to varying extents, to the type of task and/or the difficulty of the task. ERPs were recorded in 17 right-handed subjects from 10 electrodes, positioned at Oz, Pz, Cz, Fz, Fpz, 01, P3, C3, P4 and C4. The mental rotation task involved comparing 2 figures, which were rotated with respect to one another, to determine whether they were identical or mirror images. An easy condition (angle of rotation 10° to 20°) and a more difficult condition (angle of rotation 150° to 180°) was used. In mental rotation there was a centro-frontal phasic negativity, with a large peak at 380 msec (similar to the Ny peak reported by Stuss et al., 1983), and this N380 component was larger for the more difficult rotation angle stimuli. A smaller, longer latency peak was evident in mental arithmetic. It was also found that when rotation difficulty increased, the amount of negativity at centro-parietal sites in the 420-800 msec latency range was greater. This "Rotation negative shift" was largest in the left hemisphere in the parietal region at electrode site P3, consistent with the findings of Peronnet and Farrah (1989) and Wijers et al. (1989). From their experiment Ruchkin et al. (1991) concluded that both mental rotation and arithmetic elicit task specific slow wave activity.

The steady-state visually evoked potential (SSVEP) has been used as a tool in the study of the visual system (Regan, 1977), but has rarely been used in the study of human cognitive processes, and so there is little information available on SSVEP correlates of visual-spatial function. However, a study by Wilson and O'Donnell (1986) investigated the relationship between the SSVEP latency and human cognition. In particular, one of the tasks in their study was a mental rotation task, where the subjects had to mentally rotate letters or numbers and then decide whether they were oriented normally or in a mirror image. Eleven subjects were used in the experiment that included the mental rotation task (there were two experiments), with the EEG being recorded from electrodes placed in
the Oz and Pz areas. The EEG was recorded whilst subjects were randomly presented with each integer flicker frequency between 40 Hz and 59 Hz. A high correlation was found between the apparent latencies of the parietal SSVEPs and mental rotation response speeds, with this relationship being less substantial in the occipital region except for the zero degree rotation condition. The investigators interpreted these results as suggesting that the mental rotation task utilized the parietal brain areas more than the occipital brain areas. No details were given on handedness or sex of subjects, and no mention was made concerning the relationship between the SSVEP magnitude and mental rotation.

Electrophysiological correlates of cognitive functions, including visuospatial processing, have also been assessed using cortical DC-potentials, which is a new, noninvasive electrophysiological method (Altenmuller, 1989). Measurement during cognitive processes of DC-potential shifts, which are hypothesised to reflect the depolarization of large populations of cortical neurons that increase the negative DC-potential in apical dendrites, may be used to index the cerebral localization of higher mental function. Altenmuller (1989) recorded cortical DC-potentials from 14 electrodes, positioned in the frontal, central, temporal and parietal regions, during the performance of different cognitive tasks, including spatial vision. The visuospatial tasks involved the viewing of Necker cubes and similar reversing geometrical figures (Neckerfigures), as well as three-dimensional perception of random-dot stereograms visualized through red-green goggles. A total of 85 subjects (46 males, 39 females; 60 right-handers) were used in the experiments with the Neckerfigures. In contrast to a rather diffuse left hemispheric activation over large cortical areas during language and calculation tasks, a more localized right parietotemporal activation was evident in most subjects for both visuospatial tasks.

2.4 SUMMARY

The findings from the mental rotation studies; in both the overview section and the electrophysiological (core) section, are summarised separately. This is important because the evidence for a right hemisphere lateralization for other visual-spatial tasks may be reasonably strong, whereas the question as to the hemispheric lateralization for mental rotation may be less clear. In the electrophysiological section the "other visual-spatial tasks" are summarised in
another section, whilst an "other" section summarises other main points of interest in the overview.

2.4.1 Electrophysiological studies

Mental rotation studies

Few of the task relevant ERP studies have examined laterality effects, and none of the ERP studies appear to have looked at gender effects. One study (Ruchkin et al, 1991) suggested greater involvement of the parietal region in the left hemisphere, compared to the parietal region in the right hemisphere. A relatively consistent finding in the task relevant ERP studies is the late component posterior negativity (particularly at centro-parietal sites), interpreted as indicating that the posterior regions are primarily engaged during mental rotation.

The probe EP studies indicate differential hemispheric activation in the posterior region during mental rotation in both the parietal and occipital regions, interpreted as suggesting the right hemisphere is more activated than the left hemisphere. The probe EP studies did not, however, examine the anterior regions.

In the EEG studies, laterality effects have often been specifically addressed, but the reported findings show little concordance. Studies have reported left hemisphere lateralization (e.g. Ornstein et al, 1980), bilateral involvement (e.g. Gevins et al, 1979), and right hemisphere lateralization (e.g. Rebert and Low, 1978) for mental rotation. There does, however, seem to be some evidence suggesting a significant role for the parietal region in mental rotation. Very few EEG studies appear to have addressed gender effects. A study by Ornstein et al (1980) which did examine for gender effects in hemispheric lateralization found no significant difference. Furst (1976) found that subjects who performed better on visuospatial tasks (including complex mental rotation) showed relatively greater right hemisphere activation.

The only SSVEP study on mental rotation (Wilson and O'Donnell, 1986) found evidence suggesting that mental rotation significantly utilizes the parietal brain areas.
Other visual-spatial studies

Excluding mental rotation, few ERP studies have investigated ERPs in visual spatial tasks. One study (Taylor, Smith and Hammond, 1990) found significant distributional (anterior-posterior) differences of the ERPs between the sexes. With regard to probe EP studies there is some evidence suggesting right hemisphere lateralization (e.g. Galin and Ellis, 1975), but some studies have also indicated bilateral hemispheric involvement in the performance of visual-spatial tasks (e.g. Mayes and Beaumont, 1977).

Most of the EEG alpha studies suggested that the right hemisphere is more involved than the left hemisphere in the performance of visual-spatial tasks (e.g. Galin, Johnstone and Herron, 1978; Davidson et al, 1990). When compared to verbal tasks, the performance of visual-spatial tasks appeared to increase right hemisphere involvement. Most studies suggested that the right parietal and/or temporal regions were involved in the visual-spatial tasks. Gender effects were not frequently addressed, but studies by Wogan et al (1979) and Trotman and Hammond (1979) suggested that females are less lateralized than males when performing visual-spatial tasks. Ray et al (1981) found that for high spatial ability males greater right hemispheric activation was associated with better spatial problem solving. No marked relationship between lateralization and cognitive performance was found in the females.

2.4.2 Other studies

Mental rotation studies

Findings from tachistoscopic experiments have portrayed a confusing picture of hemispheric specialisation for mental rotation. Studies favouring right hemisphere lateralization (e.g. Ditunno and Mann, 1990), left hemisphere lateralization (e.g. Fischer and Pellegrino, 1988) and no hemispheric specialisation (e.g. Jones and Anuza, 1982) have been documented. A study showing a significant spatial ability by visual field interaction has also been reported (Voyer and Bryden, 1990). Subjects with high spatial ability were associated with a right visual field advantage for mental rotation. The study also supported the notion of a greater right hemisphere specialization for mental rotation in the males than the females.
Clinical studies have reported evidence of left hemisphere (e.g. Mehta, Newconibe and Damasio, 1987) and right hemisphere specialisation (e.g. Farah and Hammond, 1988) for mental rotation. The few studies involving regional cerebral blood flow (rCBF) have indicated a right hemisphere specialisation for mental rotation, but no significant sex differences in lateralization on rCBF measurements have been observed (e.g. Deutsch et al, 1988), although global overall flow has been reported to be greater in women than in men.

Many theoretical models have been put forth to explain various aspects of the cerebral processing involving mental rotation, but no consensus has emerged.

**Other**

Many tachistoscopic studies have reported sex differences in lateralization indicating greater right hemispheric lateralization for males than females during visuospatial tasks (Halpern, 1986), but some studies have found no effects of sex (e.g. Leehey et al, 1978). In clinical studies there is also evidence that males may be more right hemisphere specialized for visuospatial processing than females (e.g. McGlone and Kertez, 1973). In rCBF studies a right hemisphere lateralization in blood flow is often reported during the performance of visuospatial tasks (e.g. Gur et al, 1982). As few rCBF studies have examined gender differences, evidence has yet to emerge with respect to sex differences in lateralization.

There is accumulating evidence from neuroanatomical studies indicating a sex difference in the human corpus callosum (e.g. Hauser et al, 1989), but reports of large variations in callosal shape and size amongst individuals (Bleier, Houston and Byne, 1986) point to caution with such an interpretation. Also, there is increasing evidence that sex hormones can influence performance on cognitive tasks (e.g. Chiarello, McMahon and Schaefer, 1989). Included in this evidence have been studies finding a variation in female performance (e.g. Hampson, 1990a) and hemispheric superiority (e.g. Heister et al, 1989) on visuospatial tasks in different stages of the menstrual cycle.
CHAPTER 3

STEADY-STATE PROBE TOPOGRAPHY AND COGNITIVE PROCESSES
3.1 STEADY STATE PROBE TOPOGRAPHY (SSPT)

Techniques such as single photon emission computed tomography (SPECT) and positron emission tomography (PET), measure regional cerebral blood flow (rCBF), which is closely coupled to regional cerebral metabolism (Friedland, 1990; Ell and Holman, 1982; Reivich and Alavi, 1985). These techniques track brain function, but are sometimes of limited use when investigating functional asymmetries of the brain during cognitive tasks, as they do not possess a temporal resolution less than 30 seconds and only allow two or three repeat measures. The superconducting quantum interference device (SQUID), can map magnetic field correlates of brain function (Romani, Williamson and Kaufman, 1982; Williamson et al, 1989), and has a good spatial and temporal resolution, but it is very sensitive to noise, making it difficult to use in some environments.

Recent work at the Swinburne Centre for Applied Neurosciences (SCAN) has led to the development of Steady State Probe Topography (SSPT) (Silberstein et al, 1990). This is a novel technique possessing a temporal resolution of 10 seconds or better and the capacity to continuously measure brain electrical activity associated with cognitive processes. This technique involves examining the relationship between cognitive processes and the Steady State Visually Evoked Potential (SSVEP), as opposed to the majority of evoked potential (EP) studies examining cognitive processes, which have focused on transient EPs.

Whereas transient stimuli deliver the next stimulus after the visual system has returned to its initial state, the steady-state stimuli are delivered at a much faster rate, "so that the response to one stimulus has not died away before the next stimulus is delivered" (Regan, 1982, p.45). The idealized steady-state evoked potential can be defined "as a repetitive EP whose constituent frequency components remain constant in amplitude and phase over an infinitely long time period" (Regan, 1989, p.35). The SSVEP has been used as a tool in the study of the visual system (Regan, 1977), but its use in the study of human cognitive processes has been rare. For a comparison of transient and steady-state methods see Regan (1982) and Regan (1989).

Details of how the SSVEP is evoked, and how the SSVEP magnitude is extracted from the EEG signal is explained in detail in Chapter 4 (Method). In the SSPT, the SSVEP driving visual input (a repetitive 13 Hz task irrelevant sinusoidal flicker) is delivered by a pair of goggles positioned in front of the
subject's field of vision. As the subject performs a cognitive task whilst exposed to the flicker stimulus, the driven EEG is recorded from scalp electrodes. Recording the brain electrical activity from 64 scalp sites gives a high spatial resolution. Off-line data analysis is used to extract the component of the EEG that derived from the 13 Hz flicker stimulus. This component is known as the SSVEP. The extraction of the SSVEP involves Sine/Cosine Multiplication and subsequent integration of the Fourier coefficients, and the data is smoothed using a window function (see Silberstein et al, 1990). A thorough outline of methods for recording steady-state evoked potentials is given by Regan (1989).

The SSPT technique developed by Silberstein et al (1990) is a combination of SSVEP and the "probe EP attenuation" technique proposed by Papanicolaou and Johnstone (1984). The short Fourier integration period gives a good temporal resolution. The probe EP method, as outlined by Papanicolaou and Johnstone (1984), involves recording brain electrical responses to irrelevant stimuli during the performance of a cognitive task, and is used to "assess patterns of regional cerebral activation mediating distinct cognitive operations" (Papanicolaou and Johnstone, 1984, p.107). Hence, with SSPT, steady state potentials are evoked over a wide area of sites to produce a topographic map of activation.

The premise of the probe EP method is that increases in regional cerebral activity associated with cognitive operations induces an attenuation of potentials evoked by an irrelevant (probe) stimulus. (Silberstein et al, 1990; Papanicolaou and Johnstone, 1984). In this context, a reduction in the magnitude of the EP in a particular area is inferred as indexing increased cognitive activity for that particular area. This increase in cognitive activity is assumed to be task related. The "limited capacity" model and the "stimulus filtering" model are the two main types of models that have been proposed to explain the task-dependent attenuation of the probe EP (Papanicolaou and Johnstone, 1984). In their paper Papanicolaou and Johnstone found the limited capacity model to be a more adequate explanation of the task-dependent attenuation of the probe EP than the stimulus filtering model. The limited capacity model proposes that the "task-specific probe EP modulation reflects" a "limitation of processing resources of the cortical regions mediating the cognitive tasks" (ibid p.113). Although the theory of the probe EP method was outlined by Papanicolaou and Johnstone (1984) based on transient EP, the underlying premise of the probe EP method should equally apply to SSVEPs.
A review of studies making use of the probe EPs method was carried out by Papanicolaou and Johnstone (1984), and they concluded that the probe method was "much more versatile than the standard EP procedure" (p.128). Earlier studies using the probe method focused on studying attention and distraction, whilst more recent studies had reportedly found the technique useful in examining regional brain engagement during task performance. The probe EP method was used in the study of recovery of cognitive function, such as language, and "to the issue of assessment of neurophysiological correlates of developmental disorders, such as reading disabilities in children" (p.125).

Since the review by Papanicolaou and Johnstone (1984), the probe EP method was found to concord with measures of regional cerebral blood flow (rCBF), with greater P200 attenuation in the parietal region of the right hemisphere, during a mental rotation task, corresponding with greater increase in rCBF values in the parietal region of the right hemisphere (Papanicolaou et al, 1987).

A similar study, except that probe EPs were correlated with magnetic evoked fields (EF), found a divergence between the electrical and magnetic measures, with measurements taken from the left and right occipital region (Wilson et al, 1989). There was a smaller amplitude attenuation in the left hemisphere of the electrical P200, with respect to a baseline (probe) condition, when compared to the magnetic measures. From their study Wilson et al (1989) suggested that resource allocation in the occipital area is bilaterally symmetric, and that the hemispheric asymmetry of function reflected by the electrical P200 may be due to "asymmetric right hemisphere resource allocation occurring at more anterior locations" (p.236).

3.2 SSPT AND COGNITIVE PROCESSES

The SSPT technique is unique to SCAN, so this section, which is a review of previous work on SSPT and cognitive processes, will essentially focus on studies undertaken at SCAN.

Silberstein et al (1990) reported a study that demonstrated a correlation between the magnitude of the SSVEP and visual vigilance. Fifteen right-handed subjects were used in the study, and the EEG was recorded from 64 electrodes located on the scalp, including all the scalp positions in the International 10-20 System. A task irrelevant 13 Hz sinusoidal flicker stimulus was used to evoke the
SSVEP whilst the subject performed a visual vigilance task. The visual vigilance task consisted of observing a sequence of geometrical shapes presented on a video monitor. Each trial consisted of a series of 60 squares followed by 60 circles and another 60 squares. Three similar trials were carried out, except that in trial 3, a modification of the last circle served as a target that the subjects were challenged to identify. The subjects were ignorant as to the timing of presentation of the modified circle and also to the nature of the modification. Trial 1 was used as a familiarizing task. When comparing trials 2 and 3, it was found that the appearance of the modified circle was associated with an attenuation of the SSVEP in the occipito/parietal region. Similarly, an attenuation of the SSVEP in the centro/parietal region was found during the interval that the subjects were anticipating the appearance of the modified circle. These findings were interpreted as showing "a distinction between the cortical activation patterns occurring during different phases of a visual vigilance task" (p.337). Also, a significant SSVEP attenuation in the right prefrontal region was observed during target detection. This was interpreted as being consistent with the idea of prefrontal involvement in the mediation of attentional processes.

An examination of the topography in the SSVEP during a recognition memory task was undertaken by Pipingas, Silberstein and Currie (1992). The SSVEP in 42 right handed male subjects was elicited by a 13 Hz task irrelevant flicker stimulus. Brain electrical activity was recorded from 64 electrode sites while the subjects performed a series of tasks presented on a video monitor. Subjects were required to memorize a set of shapes presented to them before each task. Memory sets of 1, 3 and 5 shapes were used, and subjects were required to respond quickly and accurately to items from the memory set, which were presented randomly among a larger selection of shapes. It was found that a larger memory set was associated with an attenuation in the magnitude of the SSVEP and an increase in phase lag. These changes were most prominent in the occipital and parietal regions.

A study by Silberstein et al (1992) examined the effects of a computerized Wisconsin Card Sort (WCS) test on the topography of the SSVEP. Brain electrical activity was recorded in 20 male subjects from 64 scalp positioned electrodes. A 13 Hz sinusoidal task irrelevant flicker was used to elicit the SSVEP. After subjects had sorted 10 sequentially cards successfully the sort criterion in the WCS test was automatically changed, and subjects were required to determine the new criterion. It was found that the computer feedback indicating the need to
select a new sort criterion was followed by consistent attenuation of the SSVEP in the prefrontal and parietal regions. The SSVEP Topography on the WCS test has also been studied in patients with Schizophrenia by Ciorciari et al (1992), where it was found that the patients failed to show the trend of prefrontal SSVEP attenuation found in the normal control group.

The SSVEP during a continuous performance task (CPT) was examined in another study (Schier et al, 1992). A group comprising 21 right handed males and 19 right handed females was used in the study, with the SSVEP elicited by a 13 Hz task irrelevant sinusoidal stimulus. Part 1 of the CPT consisted of the subject pressing a button on the appearance of the number 5 on the screen. A regular sequence of numbers (1-5) was presented. In Part 2 of the CPT the subject had to respond by pressing a button on the appearance of a target letter. A random sequence of 5 letters would be presented on the screen at a regular rate. It was found that consistent reductions in the SSVEP magnitude was associated with the letter component of the task. These effects were found to be most prominent in the central and right fronto-temporal regions.

The SSPT technique has been applied by Wallace et al (1992) to study the degree of semantic transparency in tasks assessed as requiring performance that varies widely in terms of semantic transparency. Thirteen male subjects were used, with brain electrical activity recorded from 64 scalp sites. The SSVEP was elicited by a 13 Hz task irrelevant sinusoidal flicker stimulus. The subjects performed three task conditions which involved enumeration of randomly arranged dot patterns. In the first task condition, which produces performance which has been characterized as having a high degree of semantic transparency, the subjects were required to "count by ones" a random sequence of displays in the 6-10 numerical range. The second task condition required a very rapid type of quantification called subitizing, which has been characterised as representing a low degree of semantic transparency. The subjects were instructed to quantify "as quickly as possible without counting" displays with 1-4 dots presented. In the third condition, requiring a process of subitizing and adding, the subjects were instructed to quantify "without counting by ones" a sequence of displays in the 6-10 range. It was found that a much higher level of activity in the right parieto/temporal region was associated with subitizing, and subitizing and adding, than with counting by ones. This was interpreted as being consistent with evidence that this region mediates critical aspects of pattern recognition. It was
also found that subitizing and adding produced highly significant greater activity in the left prefrontal region than subitizing.

From the studies that have been reviewed, there is evidence to suggest that the SSPT technique is sensitive to changes in regional cerebral engagement, and can therefore be a useful tool in studying the activation patterns of the brain during cognitive processes.

3.3 ARTIFACTS

In this thesis it has been assumed that the contribution of peripheral factors to changes in the SSVEP magnitude is minimal, not significantly affecting the results. The contribution of sensory factors to changes in SSVEP magnitude was discussed by Silberstein et al (1990). They found it unlikely that changes in retinal illuminance resulting from variations in pupil size could significantly account for the observed changes in SSVEP magnitude. Increased visual attention is known to be associated with pupillary dilation, and pupillary dilation can lead to increased retinal illuminance and hence a more effective SSVEP stimulus. An increase in SSVEP magnitude would therefore be expected during increased attention if pupil size changes significantly affected the results. That increased attention leads to a reduction in SSVEP magnitude in the study by Silberstein et al (1990) suggests that changes in retinal luminance can not significantly account for the observed changes in SSVEP magnitude.

Silberstein et al (1990) also suggested that it was unlikely for changes in eye fixation position to affect the results. Their preliminary experiment reportedly showed that even relatively large changes in gaze position had no significant effects on the SSVEP.

A study by Silberstein (1991) investigated at the effects of eye movements (EOG) on the scalp topography of the SSVEP. It was found that a visual vigilance task had a pronounced effect on the SSVEP topography, but that the effect of continually alternating eye gaze between two positions had only a weak effect on the SSVEP topography. It is therefore unlikely that eye movements significantly affect the observed changes in SSVEP magnitude.

Finger movements have been associated with significant increases in rCBF, and hence local neural activation, in the contralateral sensorimotor and premotor areas and in the supplementary motor area (Colebatch et al, 1991). In this study the subjects had to press a button when responding to a target item. The
baseline task involved pressing a button approximately every 10 seconds, and the mental rotations test (MRT) involved pressing one or two buttons approximately every 20 seconds. Given that both tasks involved finger movements at a similar frequency, and that the finger movements were relatively sparse, it is unlikely that there would be any significant differences in afferent and efferent activity that would contribute to the results.

Another factor that could effect the results is eye blink artifact. The effect of eye blinks and vertical eye movements are known to produce different artifacts of the scalp EEG (Corby and Kopell, 1972). Preliminary studies at SCAN have found that eye blinks have only a weak effect on the SSVEP (Silberstein, Burkitt and Wood, 1992).

EMG artifact (or muscle artifact) can be caused by several factors, including swallowing, grimacing and frowning (Barlow, 1986). EMG activity can be a problematical artifact in EEG recordings as the frequency spectrum of EMG is broad, with power being detected at frequencies as low as 10 Hz (Davidson, 1985). As a consequence it is difficult to filter out the EMG activity so that it does not intrude into the EEG frequency bands. However, the EMG activity is not phase-locked to the 13 Hz driving signal that evokes the SSVEP. Therefore the Fourier analyser will filter out EMG activity, even at 13 Hz, which is not in phase with the 13 Hz driving signal. Hence, the SSVEP is not as prone to artifact contamination as the spontaneous EEG. There is evidence from studies at SCAN that excessive EMG does distort the SSVEP to some degree (Silberstein, Burkitt and Wood, 1992). However, it is very unlikely that such EMG artifact could have been so pervasive during the recordings as to distort the SSVEP significantly.

Another potential problem is 50 Hz artifact. At SCAN it was found that 50 Hz artifact has a negligible effect on the SSVEP (Silberstein, Burkitt and Wood, 1992). The bandwidth of the Fourier analyser is centred at 13 Hz, and the 50 Hz artifact has a negligible effect on the SSVEP since it is outside the bandpass of the Fourier analyser.

### 3.4 HYPOTHESIS

The SSPT technique is used in this thesis to examine the topography of brain electrical activity associated with cognitive processes. Using the test developed by Vandenberg and Kuse (1978), the cognitive processes associated with mental rotation will be examined.
The focus of the study is on hemispheric lateralization effects in activation during the performance of mental rotation, and on possible gender differences in the hemispheric lateralization in activation during the performance of mental rotation. Also investigated are performance level and lateralization effects in hemispheric activation, as well as gender differences in behavioural performance.

Hemispheric lateralization of activation during the performance of mental rotation is examined in this thesis, to test the hypothesis, suggested by some studies (e.g. Mehta and Newcornbe, 1991; Mehta, Newcombe and Darnasio, 1987; Fischer and Pellegrino, 1988; Corballis and Sergent, 1989; Ornstein et al, 1980), that the left hemisphere is dominant in the processing of mental rotation. If this hypothesis is correct then there should be evidence, from examining the SSVEP, of a greater activation in the left hemisphere than the right hemisphere for the mental rotation task. This will be the first time that the cerebral activation during the cognitive processing of mental rotation has been examined using SSPT, and it is anticipated that the findings of this study may help in clarifying the nature of hemispheric specialization for mental rotation.

This experiment is designed to investigate the commonly held view that males are more lateralized than females in cognitive processing of visuospatial tasks (Halpern, 1986; McGlone, 1980). If this hypothesis is correct, then one would expect the females to show a greater bilateral SSVEP activation pattern than the males. If mental rotation is a left hemisphere task then any lateralization effect should favour the left hemisphere, as opposed to those visuospatial tasks that indicate a right hemisphere dominance.

Also tested is whether the performance level of a population group has an effect on the hemispheric lateralization of activation. If the left hemisphere is dominant in mental rotation then one would expect greater left hemisphere lateralization to be associated with a higher spatial ability group than a lower spatial ability group. Again, by observing the activation pattern of the SSVEP the above hypothesis can be tested. One is also able to test the findings of studies that indicate a shift in hemispheric asymmetry between high and low spatial ability groups. For example, a study by Ray et al (1981) found that males showed a shift in hemispheric asymmetry between high and low spatial ability males, whereas females showed no such consistency. However, Ray et al (1981) examined a paper-folding task, and not a mental rotation task.

Of interest also is whether the superior male performance commonly associated with the Vandenberg and Kuse (1978) mental rotation task is evident in
this study (Goldstein, Haldane and Mitchell, 1990). By scoring the subjects' performance on the mental rotation task this study will test the above mentioned finding of male *superiority* for this task.

The Vandenberg and Kuse mental rotation task was chosen because of its reported consistency in producing sex differences in cognitive performance, and *because* of its complexity, requiring considerable effort and hence time to complete for the subject. This study is concerned with the long term tonic effects of mental rotation performance, so the Vandenberg and Kuse mental rotation task ensures that most of the subjects, in the time limit allowed for each item, would be continuously engaged in the task for the duration of the recording period.

It is essential to include a Baseline task to be used for comparative purposes, so that the difference in SSVEP magnitude between two tasks can be quantified. The difference in SSVEP magnitude between the two tasks is used as an index of the contribution in cerebral processing specifically relating one task with respect to the other. Measuring the SSVEP magnitude of only a mental rotation task would not allow the cognitive processes associated with mental rotation to be differentiated from those cognitive processes arising from general attentional demands that are applicable to a broad range of cognitive tasks (see Deutsch et al, 1987). A visual vigilance "numbers" task was chosen as the baseline task as it requires the subjects' continuous attention, but is not very demanding to perform.

The recording facilities at SCAN, which had been used successfully in other experiments, were used in this study. Before proceeding with the main experiment described in this thesis, cognitive tasks were tested on a pilot basis in two experimental protocols. The method undertaken in the main experiment is described in Chapter 4. This includes details of subjects, recording procedure and equipment, task description, off-line signal processing and analysis, statistical analysis, and also a brief summary of the method for the more relevant preliminary study.
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CHAPTER 4

METHOD
4.1 SUBJECTS

Only right handed subjects were asked to participate in this study. All subjects were asked to answer the Edinburgh Handedness Inventory (Oldfield, 1971, p.112). A total of 52 different right handed subjects (26 males, 26 females) was used. Of these, recordings from 41 subjects (20 males, 21 females) were suitable for use in cross-subject analysis of the Steady State Visually Evoked Potential (SSVEP). The reason for the omission of the other recordings was in part due to a modification of the protocol, by alteration of the reading task, as well as the addition of the last task. None of these modifications effected the tasks used in the behavioural study. Clipping of the EEG data or failure to pass an automated artifact detection procedure, constituted grounds for excluding data from further analysis and consideration.

In examination of the behavioural data all 52 subjects were used, as this increased the robustness of the outcome. This is called the "Total Population". However, to be able to correlate the behavioural data with the electrophysiological data more accurately, a separate analysis of the behavioural data was done on the 41 subjects whose SSVEP EEG data was suitable for further analysis. This group is referred to as the "SSVEP Population". The age range for the subjects was restricted to a minimum of 17 years and a maximum of 35 years. The recordings were done over a period of 5 months, from September 1991 to January 1992. A total of 5 good recordings (2 males, 3 females) was obtained only by performing a repeat run on the subject. A repeat run was done when the data recorded from the subject in the first run was not usable for analysis, and the subject was willing to do another recording at another date. In those instances the behavioural data used in the statistical analysis is taken from the first run by the subject. Subjects undergoing repeat runs were not asked to do the Part 1 practice runs again.

The education level attained by the subjects was recorded. If a person had completed year 12 at high school then the education level of that person was scored as 12. If a person was doing the first year in a tertiary institution then the education level of that person was 13, regardless of whether the person had completed the year or not. A full time postgraduate student was assigned one extra level per year, whereas a part time postgraduate student was assigned one level per two years. The current level at which the student was enrolled was always counted as one level. The education level rating is an approximate guide
due to the difficulty in classifying some of the subjects' education background under the above criteria. For example, any year the student had repeated was not taken into account.

Based on the education background of each subject, or the subjects' present course of study, a listing of the education background for each group was compiled. The group classifications were divided into Science, Engineering and Arts. Most subjects were students or staff from Swinburne University of Technology, but not exclusively so. The majority were either students enrolled in the Biophysics course in the Faculty of Applied Science, or were enrolled in the Psychophysiology course in the Faculty of Applied Science or Faculty of Arts, or were staff from the Physics Department of the Faculty of Applied Science. A small percentage (8 subjects) of the 52 subjects used were recruited from elsewhere.

The length of the recording session varied from subject to subject, but a general estimate is about 2.5 hours from the arrival of the subject to departure of the subject. The subjects were paid for their participation. The subjects were given a quick briefing about the experiment before starting, and were asked to sign an informed consent form before participating in the study. Subjects were also asked to complete another form requesting personal details, such as education, age, occupation, etc. Subjects with vision deficiencies such as myopia were used in the study, but the subjects were asked to wear their corrective glasses. As a precaution, any subject who was presently suffering from or who had previously suffered from any form of epilepsy was to have been asked to withdraw from the study. No such subjects were encountered however. From the information given by the subjects, none were suffering or had ever suffered from any neurological and/or psychiatric problem. Details regarding the subjects is found in the results section.

4.2 RECORDING PROCEDURE AND EQUIPMENT

All recordings were done in the recording room at Swinburne Centre for Applied Neurosciences (SCAN), using equipment already set up there. A diagram of the experimental set up is shown in Figure 4.1. Recordings were done using a 64 channel electrode helmet designed at SCAN (Ciorciari et al, 1987), using silver-silver chloride electrodes. These electrodes were not the conventional ones that are applied to the scalp with colloidon, but instead conductive electrode gel
Figure 4.1 Diagram of the Experimental setup used when doing the recordings.
was injected onto the scalp area underneath the electrodes after they had been
lowered onto the scalp. The benefit of this system is the much greater speed with
which the electrodes can be placed or removed. The positions of the scalp
electrodes are shown in Figure 4.2. The International 10-20 system was used, and
additional electrode positions were incorporated around the 10-20 system. The
average inter-electrode separation was 3.2 cm (Silberstein et al, 1990, p.340).
There were three different size helmets being used according to the head size of
the subject. Usually the medium size helmet was used, but occasionally it was
necessary to use the large or small size helmets. To evoke the SSVEP a pair of
goggles was mounted on the helmet in front of the subject's eyes, which gave a
13 Hz sinusoidal flicker stimulus (Silberstein et al, 1990). The flicker subtended a
horizontal angle of 160° and a vertical angle of 90°, with a modulation depth of
45%.

Each subject sat in a chair and performed tasks presented on a computer
screen. The nature of the tasks is explained in Section 4.3. Linked earlobes with
buffered inputs were used as the reference electrode, and the nose was used as the
ground reference. It has been shown previously that eye movements have a
negligible effect on the SSVEP topography (Silberstein et al, 1991). However, as
it was necessary to monitor eye movements during a reading task EOG electrodes
were also placed on the subject. Only the horizontal EOG was monitored. The
EOG signals were fed through an amplifier and viewed on a CRO. During the
read silent phase of the reading task the subject was deemed to be reading by the
examiner on the basis of examination of the subject's EOG on the CRO.

In the pre-amplifiers each of the 64 electrodes was connected to one of the
inputs of a differential amplifier, and the reference electrode was connected to the
other input. The output signal from each of these differential amplifiers was fed
through an instrumentation amplifier with a gain of 10,000 for each of the 64
channels. The signals then passed through the operational amplifiers, which could
be set to gains of 1.5, 6.5, 16 and 46. A gain of 16 was the most frequently used,
but often a gain of 7 had to be used in the event of clipping. The signal was
bandpass filtered down 3dB at 0.1 Hz and 26 Hz. The amplified and filtered data
was continuously sampled at 200 Hz per channel and digitized to an accuracy of
12-bits. The data was stored in RAM memory during the actual recording, and
was automatically written into hard disk memory immediately after the
completion of the task for subsequent off-line analysis. The data acquisition
Figure 4.2  Diagram illustrating the position of the 64 scalp electrodes. The positions marked with a square correspond to the International 10-20 system.
software was written in the DAOS language by Mark Schier at SCAN. The data acquisition computer was an IBM Compatible with an 80386 Processor.

The timing of the onset of the visual stimulus on the task computer was synchronized with the beginning of data acquisition by the use of a Metra Byte I/O Card. The task computer waited for a trigger from the Metra Byte Card, initiated by the data acquisition computer, before initiating the task presentation. The sampling was synchronous with the 13 Hz sinusoidal flickering stimulus, such that the continuous sampling started on the peak of the sine wave, and not on the zero crossing. The start time of data acquisition, as well as the time of the appearance of each new item, was recorded using the system time of day clock to an accuracy of 55 msec.

4.3 TASK DESCRIPTION

All tasks were presented on an IBM AT Compatible computer with an EGA Card. The tasks were computer driven and to time the duration of each item an external clock read through the games port was used. This clock ran at 1KHz and timing was performed to the nearest msec. For the Numbers tasks a single button response box was used. The time of pressing of a button with the right thumb, together with the reaction time, was recorded by polling the system's games port. For the other tasks a multiple button response box was necessary, with the subjects being asked to use their right or left thumb when pressing the response buttons. To accurately measure the subjects response times a multiple switch box connected to the parallel printer port of the task computer was used (Creeger, Miller and Paredes, 1990, allowing four buttons to be connected. The specific button pressed by the subject was recorded, allowing the subjects' score on the test to be calculated. Also recorded was the reaction time, which was obtained by polling the games port interfaced with the external clock. All computer programs used to time the duration of the tasks and to record the reaction times and responses were written in Microsoft C. The Numbers tasks had already been designed by Andrew Pipingas at SCAN. The other tasks were designed from scratch, and were presented using Show Partner Computer Presentation System Software by Microsoft for IBM Personal Computers and Compatibles. Details of the individual tasks are given in the sections that follow.

All tasks, except the reading task (see Appendix 7.2), were viewed by the subject from a fixed distance of 134 cm. The screen subtended an angle of 11° 43'
horizontally and $8^\circ 45'$ vertically from the subject, with the subject viewing the screen at right angles to the central fixation point of the screen. The luminance of the black task screen background was measured at 0.0 Cd/m$^2$. All tasks, except the Numbers tasks, had a black background with text or figures outlined in white. In the Numbers tasks the numbers were outlined in blue. Measurement of luminances were carried out using a Tektronix J6523-21 Narrow Angle Luminance Probe. Maximum luminances varied in the different tasks, and details are given in the sub-sections.

The duration of each task varied from 3 minutes 3 seconds (No Stimulation/Stimulation) to 3 minutes 29 seconds (Embedded Figures Task), but the duration of the actual recording of the EEG was consistently the same, being the first 3 minutes of each task. The actual experiment was divided up into two main parts. Part 1 consisted of the practice runs and Part 2 consisted of the actual recording. In Part 1, before the electrodes were positioned on the scalp, the subjects performed practice run in each of the verbal and spatial tasks (not the Numbers tasks), with the helmet on and the 13 Hz stimulus switched on, to simulate recording conditions. The main purpose of Part 1 was to familiarise the subject with the tasks, and also the recording conditions, in order to reduce any potential novelty effect. The tasks presented in Part 2, the actual recording run, were of identical nature to the practice tasks, except that the text and/or shapes presented were not identical. The tasks presented in Part 1 and Part 2 were of similar duration. Also, with respect to the four verbal and spatial tasks, half the subjects in each sex of the SSVEP Population performed them in reverse order so as to minimize any order effect. This could not be done exactly with the females as there were 21 good recordings. The three Numbers tasks remained in the same order for all subjects; that is: first, second last and last.

In this thesis, only the SSVEP data recorded from the first two Numbers tasks and the Mental Rotations Test (MRT) are presented. The SSVEP data from the other tasks will be presented elsewhere. However, since they formed part of the protocol used in this thesis, the task descriptions of the omitted tasks are included in the Appendices. The Numbers No-Motor task, however, whilst having been omitted, is described in Section 4.3.1 as it is very similar to the other Numbers tasks used. The omitted tasks are described in Appendix 7.2 (Reading Task), Appendix 7.3 (Verbal Aptitude Test) and Appendix 7.4 (Embedded Figures Task). Furthermore, results from the analysis of the Embedded Figures Task (EFT) is given in Appendix 7.5.
4.3.1 Numbers Tasks

Of the seven tasks in the protocol the first, the second last and the last task involved the subject viewing numbers as they appeared on the screen. The first task was a No Stimulation/Stimulation (NS/STIM) task. In this task the subject was asked to close his/her eyes until instructed to open them 30 seconds later. The subject was then confronted with the numbers 1, 2, 3, 4 and 5 appearing one at a time on the screen. In the first 20 seconds the numbers appeared alternately from left to right of the screen, and then appeared alternately from top to bottom of the screen for the next 20 seconds. For the remainder of the task the numbers all appeared in the centre of the screen. The subject was asked to fixate his/her eyes on the numbers wherever they appeared, and to slowly press the button on the single button response box whenever the number 5 appeared on the screen. For the first 90 seconds of the task the 13 Hz sinusoidal flicker stimulus was switched off, after which the stimulus was switched on.

The second last task was very similar to the first task. This time the subject viewed the numbers for the entire 3 minute recording period, pressing the button slowly whenever the number 5 appeared on the screen. The numbers appeared only in the centre of the screen in this task, and the flicker stimulus was on for the entire 3 minute recording period. This task was chosen as a visual vigilance task, and is called the Baseline task. This Baseline task (see Figure 4.3) was intended as a control for the Mental Rotations Test (MRT), with the difference between this Baseline task and the MRT investigated in order to minimise non-specific task effects, such as those due to general attentional demands. An active Baseline task was chosen, rather than a resting Baseline task, because of the reported lack of reliability with using a resting Baseline task (Duffy, Albert and McAnulty, 1984). The last task, which is not considered further in this thesis, was identical to the second last task, except that the subject was asked only to look at the numbers without pressing any button. This task is called the Numbers No-Motor task.

In a period of 3 minutes 7 seconds the numbers sequence 1, 2, 3, 4 and 5 repeated itself 19 times. Therefore, the subject was required to press a button approximately every 10 seconds during the Baseline task. This ensured the subjects' attention during the task, but the task itself was not very demanding. The maximum luminance was 19.2 Cd/m², associated with the number 4. The size of any number on the screen, except the number 1, was 2.0 cm horizontally.
and 1.7 cm vertically, which subtended an angle of 51' 18" horizontally and 43' 37" vertically from the subject.

5

**BUTTON PRESS**

**Figure 4.3** Illustration of the Baseline Task, in which the subject had to press a button on the appearance of the number 5.

### 4.3.2 Mental Rotations Test (MRT)

The MRT used was based on the one developed by Vandenberg and Kuse (1978). The MRT is a test of a person's ability to find the figure matching a given criterion figure within a set of dissimilar objects. The criterion figure and the correct matching figure are presented at different orientations. In the MRT the subject is actually required to choose two figures correctly matching the criterion figure, and this is usually done by trying to visualize the two-dimensional representation of the objects as being rotated in three-dimensions. Subjects were discouraged from guessing by being penalised for incorrect responses on this test.

To convert this paper-and-pen test into a computer test some minor adjustments were made. Instead of the primary object appearing on the far left, the primary object appeared in a central position (see Figure 4.4). The objects in the MRT were enlarged to a suitable size, and then scanned into a computer file using a Hewlett Packard *ScanJet* Plus scanner. The software used for this was "Scangal" operated through Microsoft Windows. The black on white background colour of the screen was later inverted to a white on black background to reduce the luminance on the task monitor screen. A similar procedure to the above was used when constructing the EFT.

The subject performed ten problems in each of the two parts, but in the actual recording period, during the first three minutes of the task, was confronted with nine problems (different screens). To make the time duration of the test comparable to the paper-and-pen MRT, the subject had 18 seconds in which to press the buttons for each of the 20 problems presented, although the screen display remained for approximately 21 seconds. The instructions in the MRT were expanded upon, but the criteria for scoring remained the same. The exact
The 2nd and 3rd objects above correctly match the criterion figure.

Figure 4.4  The top of the diagram shows an example of the original MRT problems, as developed by Vandenberg and Kuse (1978). The bottom of the screen shows how the problem was presented to the subject in the experiment. Note that the criterion figure was presented in the centre, rather than to the left. The subjects were required to press 2 of 4 buttons, to indicate which 2 of the 4 figures matched the criterion figure in the centre.
instructions read to the subject are given in Appendix 7.6. For details of the MRT see Vandenberg (1971).

The maximum luminance in the MRT was measured at 14.8 cd/m². Assuming the actual MRT figures on the screen were approximately 3 cm x 3 cm (although there was some variation), the figures subtend an angle of 1° 16' 58" horizontally and vertically from the subject.

4.3.3 Other Tasks

Apart from the recording tasks, the subjects were also asked to perform a Line Orientation Task (LOT), which was similar to the one constructed and developed by Benton, Varney and Hamsher (1978). This task was computerized by Geoff Nield at SCAN. The test consists of 30 items, and the task consists of identifying the two lines in the response choice display that correspond to the two stimulus lines. The correct lines were required to have the same angles and occupy the same location. The two stimulus lines were in fact half the length of the lines on the response card. See Figure 4.5 for illustration. There is no time limit on the LOT.

4.4 OFF-LINE SIGNAL PROCESSING AND ANALYSIS

A general outline of the signal processing method has been discussed by Silberstein et al (1990). This section will give a brief outline of the method used with the data, which is very similar to that used by Silberstein et al (1990).

To ensure that the data is not excessively contaminated with artifacts, or that the data is not just random noise, a software artifact detection procedure written by Mark Schier at SCAN was used to automatically check the raw data for artifacts. Manually checking each subjects' data file, which was in excess of 33 Mbytes, was not practicable. The first stage of artifact detection involved the construction of amplitude histograms of small epochs of data from the raw EEG, and then checking that these histograms correlated in an acceptable way to a Gaussian distribution. This procedure typically detected clipping of data, as shown in Figure 4.6.

The next stage involved doing single cycle Fourier analysis on the raw EEG, which was performed using software written by Richard Silberstein. It involved Sine/Cosine Multiplication and subsequent integration of the sine and
Figure 4.5 In this Line Orientation Task the subject had to name the two lines in the response choice display that corresponded to the two stimulus lines above the response choice display.

Figure 4.6 An example of clipping occurring in 12 seconds of raw EEG data. The histogram analysis in the first stage of artifact detection would detect the clipping and hence reject the data. The above clipping was caused by one of the reference electrodes on the ear coming loose. The vertical magnitude scale is only relative.
cosine multipliers over the one cycle integration period (Regan, 1989, p.70). The time duration of the one cycle integration period was $\frac{1}{13}$ of a second. The integrated outputs of the sine and cosine multipliers (Fourier coefficients) were saved in a file named "Rmagp", and Figure 4.7 shows a typical plot of one persons' Rmagp data. Figure 4.8 shows a section of the same persons' raw EEG data.

After this the Rmagp data was subject to another process of artifact detection and rejection, with software written by Mark Schier. This was to ensure that random noise, which might not have been detected in the first stage of artifact detection, was not accepted as valid data. This technique involved correlating the time series of each electrode on the scalp with its four nearest neighbours, and then using this correlation as a basis for either accepting or rejecting the data. If the data from a particular electrode was rejected then it was replaced by the averaged time series of its four nearest neighbours. A more detailed description of this process can be seen in Schier (1992). If too many electrodes were found to be uncorrelated with its nearest neighbours then the entire data from that subject would be discarded. The arbitrary criteria for accepting the data was that there be no more than eight bad electrodes in any of the tasks. However, the data was accepted in four subjects, where the number of bad electrodes exceeded eight in no more than two of the seven tasks. In such an instance the largest number of bad electrodes accepted was eleven for a Numbers task in one subject.

4.4.1 Window

After the second artifact rejection pass of the Rmagp data, the Rmagp data was then smoothed using a program utilizing a Window function, developed and written by Richard Silberstein. The Window length could be varied, but in the initial analysis all the data was smoothed using a 200 point Window, which is about 15.38 seconds of recording time. The square root of the sum of the squares of the Window function Fourier coefficients was evaluated. This procedure was carried out over the entire length of the Rmagp data (180 seconds), with the Window integration period being shifted one cycle each time a magnitude value of the SSVEP data had been calculated from the Window coefficients. This results in the Window periods overlapping, as there are 13 cycles per second, and the window length is 15.38 seconds. By decreasing the Window width one can obtain better temporal resolution of brain electrical processes, but this results in a poorer
Figure 4.7 Illustration of Rmagp data, which consists of the integrated outputs of the 13 Hz sine and cosine Fourier coefficients over the one cycle integration period. The graph shows the entire 180 seconds of the Baseline task from electrode 60 in subject 35. The vertical magnitude scale is only relative.

Figure 4.8 Illustration of the raw EEG from subject 35. The graph shows the first six seconds of the Baseline task from electrode 60. The vertical magnitude scale is only relative.
signal to noise ratio. In choosing a suitable Window period one makes the above trade off in determining the optimum length. The output of the resultant SSVEP magnitude was stored in polar form in a file named "Rlock", along with the SSVEP phase information. Figure 4.9 shows the Rlock file time series obtained by using a 200 point Window on the Rmagp data in Figure 4.7. This Rlock data file is shorter than the Rmagp data file by the length of the window period (i.e. 2336 cycles (180 seconds of data) - 200 cycles (15.38 seconds of window length)). Essentially, the first and last part of the data file have each been truncated by half a window width. The effect of decreasing the window width on the same Rmagp data (Figure 4.7) is shown in Figure 4.10.

4.4.2 Normalizing Procedure

As described in Silberstein et al (1990) it is necessary to normalize the data when doing a cross subject average of the data because of the large variation in the magnitude of the SSVEP from one subject to another. If this is not done the data can be skewed by individuals with a large SSVEP magnitude. Task 5, being the pressing of a button when the number 5 appeared on the screen, was chosen as the normalizing (or Baseline) task in a static analysis of the data. This task was a simple one to perform, while still demanding the subjects' attention. The normalizing and cross-subject averaging of the data presented in the results section was performed on rlock data windowed with a 200 cycle window width. Before the normalizing and cross-subject averaging the temporal variation of the data was collapsed into one single point for each electrode.

The normalization procedure of the data was developed by Richard Silberstein. The data was normalized by first calculating a mean value for each electrode, in the SSVEP magnitude and SSVEP phase time series in Task 5, for each subject. In obtaining these mean values the data, stored in polar form (4.2), was converted to cartesian form (4.1) and then the mean real and mean imaginary part of the complex number across the entire time series was derived and converted back to polar form.
Figure 4.9 Illustration of Rlock data obtained by smoothing the Rmagp data shown in Figure 4.7 with a 200 point Window. Note that the graph is about 15 seconds shorter. The vertical magnitude scale is only relative.

Figure 4.10 Illustration of Rlock data obtained by smoothing the Rmagp data in Figure 4.7 with a 50 point Window, making it about 4 seconds shorter. Note that it is much noisier than the 200 point Window used in Figure 4.9. The vertical magnitude scale is only relative.
Cartesian form of Complex number:
\[ z = \text{Re} + \text{Im} \times i \]

Polar form of Complex number:
\[ z = r(\cos P + i \sin P) \]

where \( \text{Re} = r \cos P = \text{real part} \)
\( \text{Im} = r \sin P = \text{imaginary part} \)
\( r = (\text{Re}^2 + \text{Im}^2)^{1/2} = \text{magnitude} \)
\( P = \arctan(\text{Im}/\text{Re}) = \text{phase (radians)} \)

(Jeffrey, 1985)

With respect to the SSVEP magnitude the mean of these 64 values, which correspond to the 64 electrode positions, were used to normalize each subjects' SSVEP magnitude. The mean of the 64 SSVEP magnitude values was obtained by averaging the real and imaginary components of the 64 values and converting back to polar form as described above. The single value obtained for the average SSVEP magnitude was divided into every SSVEP magnitude value in the time series of the other tasks.

With the mean SSVEP phase each of the 64 individual phase values obtained was used to normalize the SSVEP phase of the corresponding electrode in the other tasks. This was done by setting the phase of the MRT task to a value equivalent to the difference in phase between the MRT and Normalizing task, and then setting the SSVEP phase value of the Normalizing task to zero. Only the difference in SSVEP phase was examined in the subject group, not the absolute values.

The cross-subject averaging for the SSVEP phase was performed by averaging the corresponding vectors of all the subjects for each data point. The cross-subject average for the SSVEP magnitude was obtained by averaging the SSVEP magnitude (in polar form) of all the subjects for each data point.

4.4.3 Topographic Mapping

To aid in the analysis of the SSVEP data, topographic mapping was used. The magnitude and phase information in the SSVEP data may be displayed in various ways using topographic maps. Furthermore, maps may be animated by constructing a map for each point in the time series length of the data under consideration, and then stringing these maps together into an animated sequence.
using an animation package. Because this study was concerned with the long term tonic effects of mental rotation performance, topographic maps known as "Pointmaps" were mostly used to look at the data.

Pointmaps display the average of the SSVEP across the entire time series of the particular task in question, giving 64 values which represent the mean for each of the 64 electrodes in the time series. Whilst the Pointmaps possess a good spatial resolution, they do not portray any temporal information. The standard topographic Pointmap displays the spatial variation in the mean SSVEP magnitude for a task. Because it was necessary to look at the difference in SSVEP magnitude between two tasks, thereby indexing the contribution in cerebral processing of one task with respect to the other, Pointmaps from two separate tasks were used, subtracting the pointmap of one task from the pointmap of another task. These difference Pointmaps are known as "Difference" maps. In order to examine the effects of the MRT task with respect to the Baseline task, the MRT pointmap were subtracted from the Baseline pointmap. By using Difference maps, non-specific task effects, such as those due to general attentional demands, can be minimised.

Although the focus of this thesis is on the SSVEP magnitude data, the SSVEP phase pointmaps are also displayed in the results section. There is uncertainty as to the significance of the SSVEP phase changes, however these are included to indicate what specific effects arose. In interpreting the SSVEP magnitude data the Probe Evoked Potentials theory (Papanicolaou and Johnstone, 1984) was used, as described in Chapter 3. A decrease in SSVEP magnitude is interpreted to be indicative of increased regional cortical activity. With the pointmaps, cooler colours (blue) indicate smaller SSVEP magnitude. With the difference maps, hotter colours (red) indicate greater SSVEP attenuation of the MRT task relative to the Baseline task. The value given of the SSVEP magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. The SSVEP phase is the phase of the evoked potentials in relation to the 13 Hz sinusoidal driving signal (induced flashes). The value given of the SSVEP phase is expressed as the difference in phase between the visual-spatial task and the Baseline task. With respect to SSVEP phase, 1 radian is equivalent to a latency of 12.24 msec. In the SSVEP phase pointmaps cooler (blue) colours indicate larger phase lag (increased latency), whereas with the SSVEP phase difference maps hotter (red) colours demonstrate larger phase lag (increased latency). As the SSVEP phase is
expressed as the difference in phase between two tasks, the SSVEP phase difference maps are the negative of the SSVEP phase pointmaps.

Topographic maps are also made of the square root of Hotelling's $T^2$ ($T$) parameter (see Section 4.5.2), where the pointmaps from the MRT task were compared with the pointmaps from the Baseline task in order to determine any consistent effects across the subject group. The square root of Hotelling's $T^2$ was used, rather than Hotelling's $T^2$, as it allowed smoother contours of the Iso-$T$ values on the topographic maps. The square root of Hotelling's $T^2$ ($T$) parameter is referred to as Hotelling's $T$ for simplicity. These maps are referred to as "Probability" maps or "Hotelling's $T$ Probability maps".

The Topographic maps were obtained by using a program utilizing an interpolation technique based on spherical splines developed and written by Peter Cadusch at SCAN (Cadusch, Breckon and Silberstein, 1992). This technique assumes a multi-layered sphere model as representing the conduction properties of the head, and in addition to interpolating the scalp data, allows a smooth estimate of the potential on the cortex to be derived directly from the scalp data.

4.5 STATISTICAL ANALYSIS

4.5.1 Behavioural Data

To examine the significance of the difference between the two means for the male and female behavioural scores, an Independent Two-Tailed Student's $t$-test was performed (Ferguson, 1981, p.178). In comparing the two standard deviations of the male and female populations an analysis of Variance was performed using the F-test (Regier, Mohapatra, and Mohapatra, 1982, p.136).

4.5.2 SSVEP Data

To test whether there was a consistent difference between two tasks, usually the Baseline task and another task, the square root of Hotelling's $T^2$ ($T$) was calculated (referred to as Hotelling's $T$). The Hotelling's $T^2$ involves "testing a mean outcome vector or the difference between two vectors of mean scores on dependent measures against corresponding population mean vectors" (Harris, 1975, p.67). The Hotelling's $T^2$ has a sampling distribution like the F-distribution if the dependent measures have been sampled from a multivariate normal
distribution. The computer program to do this was written by Richard Silberstein. The Hotelling's $T^2$ takes into account both the SSVEP magnitude and SSVEP phase, and is here used as an exploratory statistical analysis in significance probability mapping (Duffy, Bartels and Burchfiel, 1981; Duffy et al., 1990).

**Bivariate** Hotelling's $T^2$ was used to estimate the statistical strength of the task effect at each electrode. The Hotelling's $T^2$ considers real and imaginary components which may not be independent. Here it is used as an exploratory technique. Multivariate techniques such as ANOVA are inappropriate in the light of the fact that we have more electrodes than subjects (Blair and Karniski, 1993).

The Hotelling's T parameter gives a guide to the consistency of the SSVEP data, and is used for both pointmap data, as well as time series data. In the results section the Hotelling's T parameter and "p" value are given in order to compare the consistency between different subject groups. This should be taken as only a relative comparison. Although a larger Hotelling's T parameter indicates greater consistency, because the 64 electrodes are not independent it would not be correct to use the "p" values obtained from the Hotelling's T parameter without corrections for multiple measures.

### 4.6 PRELIMINARY STUDY

The presentation of the behavioural data from the Preliminary Study is intended as an aid to the interpretation of the behavioural scores from the main study. Although the tasks were similar, the Preliminary Study did not involve any recording of the EEG. In the Preliminary Study only behavioural data was examined, and the tasks were subject driven, with no time limit imposed on the subject when responding to each item. There were also more items presented in the Preliminary Study in two (VAT, EFT) of the three tasks (VAT, EFT, MRT) investigated. In addition, the scoring of the MRT was different as the subject had to choose two targets, thus only a score of 0 or 2 was possible for each item. The majority of subjects in the preliminary subjects were from a Science educational background, and were either student or staff from Swinburne University of Technology. The Preliminary Study gives information on reaction time data, in addition to the scores on each task, and is therefore included.
5.1 INTRODUCTION

5.2 SUBJECTS

Two subject groups were analyzed separately with respect to the behavioural data. In addition to the Total Population and the SSVEP Population, behavioural data from the Preliminary Study is also discussed.

5.2.1 Total Population

There were 52 right handed subjects (26 males, 26 females) used in the study (mean age = 21.87 yr., S.Dev. = 4.62). For females the age range was 17 to 33 years (mean = 20.85 yr., S.Dev. = 4.14). For males the age range was 18 to 35 years (mean = 22.88 yr., S.Dev. = 4.84). The difference between the mean age of the male and female groups was not significant (t = 1.584, d.f. = 50, p > .05), and there was significant difference between the two standard deviations (ANOVA: F = 1.367, d.f. = 25, 25, p > .05).

The mean education level (as defined in Section 4.1) for the 52 subjects was 14.00 years (S.Dev. = 1.71). The mean education level of the 26 females was 13.42 years (S.Dev. = 1.01). The mean education level of the 26 males was 14.58 years (S.Dev. = 2.04). The difference between the mean education level of the male and female groups was significant (t = 2.446, d.f. = 50, p < .05), and there was a significant difference between the two standard deviations (ANOVA: F = 4.080, d.f. = 25, 25, p < .001).

With the females the education background (as defined in Section 4.1) was 14 Science, 1 Engineering and 11 Arts subjects. With the males the education background was 20 Science, 2 Engineering and 4 Arts subjects.

5.2.2 SSVEP Population

The 41 subjects (20 males, 21 females) of the SSVEP population (mean age = 21.95 yr., S.Dev. = 4.18) were subjects from the Total Population for whom SSVEP recordings passed the artifact rejection analysis. For females the age range was 17 to 31 years (mean = 20.76 yr., S.Dev. = 3.58). For males the age range was 18 to 32 years (mean = 23.20 yr., S.Dev. = 4.40). The difference between the mean age of the male and female groups was not significant (t =
1.868, d.f. = 39, p > .05), and there was no significant difference between the two standard deviations (ANOVA: F = 1.511, d.f. = 19, 20, p > .05).

The mean education level for the 41 subjects was 14.12 years (S.Dev. = 1.85). The mean education level of the 21 females was 13.38 years (S.Dev. = .95). The mean education level of the 20 males was 14.4 years (S.Dev. = 2.35). The difference between the mean education level of the male and female groups was not significant (t = 1.765, d.f. = 39, p > .05), but there was a significant difference between the two standard deviations (ANOVA: F = 6.119, d.f. = 19, 20, p < .001).

With the females the education background was 12 Science, 1 Engineering and 8 Arts subjects. With the males the education background was 15 Science, 1 Engineering and 4 Arts subjects.

5.2.3 Preliminary Study

A total of 16 right handed subjects (8 males, 8 females) was used in the preliminary study (mean age = 26.00 years, S.Dev. = 6.83). For females the age range was 19 to 30 years (mean = 23.88 yr., S.Dev. = 4.37). For males the age range was 21 to 48 years (mean = 28.13 yr., S.Dev. = 8.07).

5.3 BEHAVIOURAL RESULTS

This section presents the results of the statistical analysis of the behavioural data from the Total Population, SSVEP Population and Preliminary Study, together with the scores from the different Performance Groups. For two subjects (1 male, 1 female) the exact score for the MRT is unavailable due to the failure of one button on the multiple button response box. These two subjects have been excluded from the analysis of the behavioural scores. Both were part of the SSVEP Population, and on examination of the responses with the other three buttons both subjects performed poorly. One male subject from the SSVEP Population was also excluded from the LOT because of previous familiarity with the task.
5.3.1 Total Population

The results are summarised in Table 5.1. The mean score for the males on the Mental Rotations Test (MRT) was 55.00% (S.Dev. = 17.15) whereas the mean score for the females on the MRT was 41.60% (S.Dev. = 13.55). A significant difference favouring a better performance by the males was found with the MRT when comparing the means of the male and female groups (t = 2.812, d.f. = 48, p < .01). There was no significant difference between the two standard deviations (ANOVA: F = 1.602, d.f. = 24, 24, p > .05).

The mean score for the males on the Line Orientation Task (LOT) was 93.47% (S.Dev. = 5.83) compared to a mean score for the females on the LOT of 82.30% (S.Dev. = 12.40). There was a significant difference between the two means of the male and female groups in favour of better male performance on the LOT (t = 3.549, d.f. = 49, p < .001), and a significant difference between the two standard deviations (ANOVA: F = 4.519, d.f. = 25, 24, p < .001).

5.3.2 SSVEP Population

A summary of the results can be found in Table 5.2. The mean score for the males on the MRT was 57.10% (S.Dev. = 15.58) compared to a mean score for the females on the MRT of 41.75% (S.Dev. = 14.45). There was a significant difference between the means of the male and female groups favouring a better performance by the males on the MRT (t = 2.839, d.f. = 37, p < .01), but no significant difference between the two standard deviations (ANOVA: F = 1.163, d.f. = 18, 19, p > .05).

The mean score for the males on the LOT was 93.87% (S.Dev. = 5.93) compared to a mean score for the females on the MRT of 79.83% (S.Dev. = 17.47). There was a significant difference between the means of the male and female groups in favour of a better male performance on the LOT (t = 2.948, d.f. = 38, p < .01), and a significant difference between the two standard deviations (ANOVA: F = 3.08, d.f. = 20, 18, p < .001).

5.3.3 Performance Groups Scores

The subjects in the SSVEP Population were also divided into Performance groups, based on their performance during Part 2 of the MRT. The performance
### Table 5.1 Tabulation of the results of the behavioural scores from the Total Population. The males performed significantly better on the MRT and LOT than the females, and the variance between the male and female results was significantly different on the LOT.

<table>
<thead>
<tr>
<th>Task</th>
<th>Items</th>
<th>Males Mean</th>
<th>S.Dev</th>
<th>Females Mean</th>
<th>S.Dev</th>
<th>Total Mean</th>
<th>S.Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRT</td>
<td>20</td>
<td>55.00a</td>
<td>17.15</td>
<td>41.60a</td>
<td>13.55</td>
<td>48.30</td>
<td>16.85</td>
</tr>
<tr>
<td>LOT</td>
<td>30</td>
<td>93.47b</td>
<td>5.83</td>
<td>82.306</td>
<td>12.40</td>
<td>87.77</td>
<td>11.23</td>
</tr>
</tbody>
</table>

*a* t-test: significant difference between the means *(p < 0.01).*  
*b* t-test: significant difference between the means *(p < 0.001).*  
*c* F-test: significant difference in variance *(p < 0.001).*

### Table 5.2 Tabulation of the results of the behavioural scores from the SSVEP Population. The males performed significantly better on the MRT and LOT than the females, and the variance between the male and female results was significantly different on the LOT.

<table>
<thead>
<tr>
<th>Task</th>
<th>Items</th>
<th>Males Mean</th>
<th>S.Dev</th>
<th>Females Mean</th>
<th>S.Dev</th>
<th>Total Mean</th>
<th>S.Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRT</td>
<td>20</td>
<td>57.10a</td>
<td>15.58</td>
<td>41.75a</td>
<td>14.45</td>
<td>49.23</td>
<td>16.88</td>
</tr>
<tr>
<td>LOT</td>
<td>30</td>
<td>93.87b</td>
<td>5.93</td>
<td>79.83b</td>
<td>17.47</td>
<td>86.50</td>
<td>15.03</td>
</tr>
</tbody>
</table>

*a, b* t-test: significant difference between the means *(p < 0.01).*  
*c* F-test: significant difference in variance *(p < 0.001).*
at the time of the actual recording was used for all the subjects in the Performance groups. The Performance Groups consisted of Best Performance Males (BPM), Best Performance Females (BPF), Worst Performance Males (WPM) and Worst Performance Females (WPF). All Performance Groups consisted of 8 subjects each. Subjects excluded were either borderline between the Best and Worst Performance groups or their exact scores were unavailable.

A Compatible Performance Males (CPM) group was also constructed. Eight males were chosen so that their scores matched the BPF group, therefore the scores of the CPM group had a similar distribution to that of the BPF group. Furthermore a Best Performance All (BPA) group was also constructed, consisting of the 8 subjects with the best performance regardless of sex. In the MRT there were 6 males and 2 females in the BPA group.

The scores (in %) of the various Performance Groups on Part 2 of the MRT was as follows: Best Performance Males (mean = 75.0 %, S.Dev. = 12.3); Best Performance Females (mean = 60.0 %, S.Dev. = 12.3); Worst Performance Males (mean = 45.0 %, S.Dev. = 10.0); Worst Performance Females (mean = 30.0 %, S.Dev. = 7.9); Compatible Performance Males (mean = 60.0 %, S.Dev. = 11.2); Best Performance All (mean = 79.4 %, S.Dev. = 9.8).

5.3.4 Preliminary Study

The results are summarised in Table 5.3. The mean score for the males on the MRT was 78.75 % (S.Dev. = 8.57) compared to a mean score for the females on the MRT of 71.90 % (S.Dev. = 24.10). There was no significant difference between the mean scores of the male and female groups on the MRT (t = .744, d.f. = 14, p > .05), but there was a significant difference between the two standard deviations (ANOVA: F = 7.908, d.f. = 7, 7, p < .01). The MRT task in the Preliminary study was scored differently because there was no time limit imposed on the performance of the items in the tasks in this study.

The mean total task time for the males on the MRT was 690.042 sec (S.Dev. = 258.908) compared to the mean total task time for the females on the MRT of 717.073 sec (S.Dev. = 256.181). There was no significant differences on the mean total task times between the male and female groups on the MRT (t = .210, d.f. = 14, p > .05), and no significant difference between the two standard deviations (ANOVA: F = 1.021, d.f. = 7, 7, p > .05).
Table 5.3 Tabulation of the results from the MRT of the behavioural scores, total task times and average response rate per item from the Preliminary Study. There was no significant difference in performance between the males and females, but the variance between the male and female scores significantly different. No significant difference in the total task times between the male and female groups was found. No significant difference in the mean average response rate per item between the male and female groups was found, but there was a significant difference in the variance between the males and females.
The mean average response rate per item for the males on the MRT was 34.502 sec (S.Dev. = 20.862) compared to the mean average response rate per item for the females on the MRT of 35.854 sec (S.Dev. = 24.683). There was no significant differences on the mean average response rate per item between the male and female groups on the MRT (t = .529, d.f. = 318, p > .05), but there was a significant difference between the two standard deviations (ANOVA: F = 1.400, d.f. = 159, 159, p < .05).

5.4 SSVEP TOPOGRAPHIC DATA

The cross-subject average topographic data of the SSVEP Population and the Performance Groups are presented. This data is derived from the rlock data file, which was smoothed using a 200 point window (15.38 seconds) before the temporal resolution was collapsed into one point for each electrode, and a cross-subject average of the data was performed. The topographic data includes pointmaps, difference maps and Hotelling's T probability maps (see Section 4.4.3 and 4.5.2 for detailed explanation of these maps). The data is a reduction of the mean SSVEP magnitude and mean SSVEP phase of each of the 64 electrodes for the entire 3 minute recording period, where the SSVEP magnitude and SSVEP phase of each electrode has been collapsed into one point. Temporal information is not considered in this section.

The SSVEP magnitude value is expressed in terms of the mean SSVEP magnitude at all 64 sites. The value of the SSVEP phase is expressed as the difference in phase between the visual-spatial task (MRT) and the Baseline task. With respect to the SSVEP phase 1 radian is equivalent to a latency of 12.24 msec. In the SSVEP phase pointmaps cooler (blue) colours indicate larger phase lag (increased latency), however in the SSVEP phase difference maps hotter (red) colours demonstrate larger phase lag (increased latency).

In the SSVEP magnitude pointmaps hotter colours indicate larger SSVEP magnitude for the particular task, whereas with respect to the SSVEP magnitude difference maps, hotter colours indicate smaller SSVEP magnitude for the MRT with respect to the Baseline task.

With the Hotelling's T probability maps hotter colours' indicate greater Hotelling's T values, which imply a greater "p" value. The single Hotelling's T value given in the text (e.g. T = 8.4, d.f. = 19, 1, p < .001 on p.93) for each subject group was the maximum value for the 64 electrodes in that particular
probability map. The Iso-T values illustrated on the probability maps correspond to single comparison "p" values of 1 %, 0.5 % and 0.1 %.

The descriptions in this section should be read in conjunction with the topographic maps, as the descriptions are approximations due to the overlap of different regions displaying the same effect. With the SSVEP Population, maps are displayed for all 41 subjects analysed as a combined group (All group). Maps are also presented for the 20 males and 21 females analysed as two separate groups.

5.4.1 SSVEP Population and No Stimulation/Stimulation

Pointmaps of No Stimulation/Stimulation

The pointmaps in Figure 5.1 illustrate the difference in the SSVEP magnitude when the 13 Hz Sinusoidal Flicker stimulus was off and on. See Section 4.4.3 for a detailed explanation of pointmaps. The No Stimulation/Stimulation (NS/STIM) recordings were always performed first in the protocol. The three No Stimulation pointmaps in the left hand column of Figure 5.1 show the endogenous magnitude. The right hand column shows the SSVEP magnitude when the stimulus was on. A difference in SSVEP magnitude between the No Stimulation and Stimulation pointmaps is evident. A much larger SSVEP magnitude was recorded when the stimulus was on, compared with the stimulus off condition, for Males, Females and All of the SSVEP Population. The increase in SSVEP magnitude was most significant in the occipito/parietal regions when the stimulus was on.

With the No Stimulation/Stimulation recordings the period of averaging for the two recordings was considerably less than 3 minutes (70 seconds each), since they were both performed within the same 3 minute recording period. The SSVEP magnitude in these two recordings may possibly be slightly smaller if they had been averaged for the same time period as the other tasks. However, the main point of including the No Stimulation and Stimulation recordings was to show the contrast between the stimulus off and on conditions, rather than as a comparison to the other tasks.
Figure 5.1 The topographic maps illustrate the difference in the SSVEP magnitude distribution when the 13 Hz Sinusoidal Flicker stimulus is switched off and on. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 1 illustrates the endogenous distribution of the SSVEP in the No Stimulation condition. Column 2 illustrates the distribution of the SSVEP in the Stimulus condition.
5.4.2 SSVEP Population and Mental Rotation

**Pointmaps of Visual Vigilance Task**

The pointmaps in the left hand column in Figure 5.2 illustrate the SSVEP magnitude from the Visual Vigilance task (Baseline task) of the Males, Females and All of the SSVEP population. Because of the normalization procedure (see Section 4.4.2) the Visual Vigilance task pointmaps of the SSVEP phase were zero, and were therefore not included in the diagram. This exclusion also applies to all subsequent descriptions involving the Visual Vigilance task.

The topography of the three pointmaps is similar in that the maximum SSVEP magnitude occurred in the occipito/parietal region in all three pointmaps. The effect was larger in the Females than the Males. With the Females and All group this effect was more pronounced in the left occipitoparietal region than the right occipitoparietal region, whereas no significant laterality effect in this region was found in the Males.

**Pointmaps of Mental Rotations Test**

The pointmaps in the centre column of Figure 5.2 illustrate the SSVEP magnitude from the MRT of the Males, Females and All of the SSVEP population. The SSVEP magnitude in the occipitoparietal region of all three groups was much larger than in any of the other regions. No significant laterality effect in the occipitoparietal region was observed in any of the MRT SSVEP magnitude pointmaps, except for a slight left hemisphere (LH) lateralization in the females.

Because the MRT SSVEP phase pointmaps are the negative of the SSVEP phase difference maps, due to the normalization procedure, the MRT SSVEP phase pointmaps shown in the right hand column will be described in the difference maps section, as SSVEP phase difference maps, to avoid repetition. This deferral will apply to all subsequent descriptions involving the MRT SSVEP phase pointmaps or EFT SSVEP phase pointmaps.
Figure 5.2 The topographic maps are from the Males, Females and All groups of the SSVEP Population. Column 1 illustrates the distribution of the SSVEP magnitude during the Visual Vigilance (Baseline) task. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 2 illustrates the equivalent distribution during the MRT with Column 3 illustrating the distribution of the SSVEP phase during the MRT referenced to the Visual Vigilance task phase.
Difference Maps

The difference maps of SSVEP magnitude and SSVEP phase shown in the left and centre column respectively of Figure 5.3 are the MRT task, of the Male, Female and All groups of the SSVEP Population, subtracted from their respective Baseline task (Visual Vigilance task). To examine the effects of the MRT task with respect to the Baseline task, the MRT pointmap was subtracted from the Baseline pointmap. See Section 4.4.3 for a detailed explanation of difference maps.

The topography of the All group SSVEP magnitude difference map indicates significant SSVEP magnitude reductions, with respect to the Baseline task, in the occipitolparietal, frontal and left temporolparietal regions. There was a very weak LH lateralization effect in SSVEP magnitude reduction in the temporal region, but overall no noticeable laterality effect was evident in the All group. There was a slight SSVEP magnitude increase in the centro/parietal region in the All group.

The topography of the Male group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the occipitolparietal, and frontal regions. Overall no prominent laterality effect in SSVEP magnitude reduction was evident in the Males, although there was a LH lateralization in the occipito/parietal region. There was a noticeable SSVEP magnitude increase in the centro/parietal region in the male group.

The topography of the Female group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in all areas save the centrolparietal and prefrontal regions. There was a very weak LH lateralization effect in SSVEP magnitude reduction in the temporal region, but overall no noticeable laterality effect was evident in the Female group.

The SSVEP phase difference maps show more specific effects. Males demonstrated the largest phase lag (increased latency) in the left temporolparietal region while Females demonstrated the largest phase lag in the right temporo/parietal region. Also, in the All group, no significant hemispheric difference in the SSVEP phase distribution was evident between the left and right hemispheres. In all cases, frontal regions showed a phase advance (decreased latency).
Figure 5.3 The topographic maps are from the Males, Females and All groups of the SSVEP Population. The Maps illustrate the difference in the SSVEP associated with the Visual Vigilance (Baseline) and MRT tasks. Column 1 indicates the magnitude differences. Column 2 indicates the phase differences, while Column 3 illustrates the distribution of the square root of Hotelling’s $T^2$ ($T$) based on paired comparison between the two tasks. The Iso-$T$ values illustrated correspond to single comparison $p$ values of 1 $\%$, 0.5 $\%$ and 0.1 $\%$. 
Hotelling's T Probability Maps

The Hotelling's T probability maps illustrated in the right hand column of Figure 5.3 are the MRT task, of the Males, Females and All of the SSVEP population, compared with their respective Baseline task (Visual Vigilance task). These maps were used as an exploratory analysis in statistical significance probability mapping. See Section 4.4.3 and Section 4.5.2 for a more detailed explanation of Hotelling's T probability maps. The topography of the probability maps indicates that the most consistent effects were in the frontal and temporoparietal regions for all three groups, with the Females showing more consistency than Males, especially in the temporoparietal regions. In the prefrontal region the Males showed greater consistency than the Females. All three groups displayed a lack of consistency in the centroparietal and occipital regions, especially the Males.

Overall, the observed effects were stronger in the Females ($T = 8.4$, d.f. $= 19, 1$, $p < .001$) than the Males ($T = 5.8$, d.f. $= 19, 1$, $p < .001$). The effect in the 41 subject All group was conservatively estimated with respect to the Male and Female groups, as the degrees of freedom used for the F-distribution value was the same as that used for the 20 subject Male group ($T = 7.7$, d.f. $= 19, 1$, $p < .001$).

5.4.3 Best Performance Groups and the MRT

In order to examine whether level of spatial ability may be a confounding factor in the results, the subjects in the SSVEP Population were divided into performance groups (8 subjects in each group). The results of the higher spatial ability subjects (Best Performance groups) are presented.

Pointmaps of Visual Vigilance Task

The pointmaps in the left hand column in Figure 5.4, illustrating the SSVEP magnitude from the Visual Vigilance task, were from the Best Performance Male (BPM) and Female (BPF) groups, as well as the Compatible Performance Males (CPM) group with respect to the BPF group (see Section 5.3.3).
Figure 5.4 The topographic maps are from the Best Performance Males (BPM), Best Performance Females (BPF) and Compatible Performance Males (CPM) groups. Column 1 illustrates the distribution of the SSVEP magnitude during the Visual Vigilance (Baseline) task. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 2 illustrates the equivalent distribution during the MRT with Column 3 illustrating the distribution of the SSVEP phase during the MRT referenced to the Visual Vigilance task phase.
The topography of the three pointmaps was similar in that the maximum SSVEP magnitude occurred in the occipito-parietal region in all three pointmaps. This effect was more pronounced in the BPF than the BPM and CPM. No significant laterality effect in the occipito-parietal region was observed in any of the groups except for a weak LH lateralization in the BPF. The BPM showed a larger SSVEP magnitude in the left temporo-parietal region than the right temporo-parietal region.

**Pointmaps of Mental Rotations Test**

The pointmaps in the centre column in Figure 5.4, illustrating the SSVEP magnitude from the MRT, were from the BPM, BPF and CPM groups. The SSVEP magnitude in the occipito-parietal region of the BPM, BPF and CPM groups was much larger than in any of the other regions. No significant laterality effect in the occipito-parietal region was observed in any of the SSVEP magnitude pointmaps, except for a weak LH lateralization in the BPF. The MRT SSVEP phase pointmaps shown in the right hand column will be described in the difference maps section as the SSVEP phase difference maps.

**Difference Maps**

The difference maps of SSVEP magnitude and SSVEP phase shown in the left and centre column respectively of Figure 5.5 are the MRT task, of the BPM, BPF and CPM groups, subtracted from their respective Baseline task.

The topography of the BPM group SSVEP magnitude difference map indicates significant SSVEP magnitude reductions, with respect to the Baseline task, in the frontal, left temporo-parietal and occipito-parietal regions. There was a noticeable LH lateralization effect in SSVEP magnitude reduction in the temporo-parietal region. The occipital and centrol-parietal regions showed a significant SSVEP magnitude increase.

The topography of the BPF group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in all areas save the centrol-parietal region. A noticeable RH lateralization effect in SSVEP magnitude reduction was evident in the temporo-parietal region. The centrol-parietal region showed a slight SSVEP magnitude increase.
Figure 5.5 The topographic maps are from the Best Performance Males (BPM), Best Performance Females (BPF) and Compatible Performance Males (CPM) groups. The Maps illustrate the difference in the SSVEP associated with the Visual Vigilance (Baseline) and MRT tasks. Column 1 indicates the magnitude differences. Column 2 indicates the phase differences, while Column 3 illustrates the distribution of the square root of Hotelling’s $T^2$ ($T$) based on paired comparison between the two tasks. The Iso-T values illustrated correspond to single comparison $p$ values of 1%, 0.5% and 0.1%. 
The topography of the CPM group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, only in the occipito/parietal region. No significant laterality effect in SSVEP magnitude reduction was evident.

In examining the SSVEP phase difference maps the BPM demonstrated the largest phase lag in the right temporolparietal region. The BPF demonstrated the largest phase lag in both the right and left temporolparietal regions, as did the CPM. The BPF showed a noticeable phase advance in the frontal region, particularly the prefrontal region. The CPM showed the most noticeable phase advance in the prefrontal and right temporolparietal regions. The most noticeable phase advance in the BPM was observed in the right temporolparietal region.

**Hotelling's T Probability Maps**

The Hotelling's T probability maps illustrated in the right hand column of Figure 5.5 are the MRT task, of the BPM, BPF and CPM groups, compared with their respective Baseline task. The topography of the probability maps indicate that the most consistent effects were in the frontal and right temporolparietal regions for the BPF. In the BPM the most consistent effects were observed in the left temporolparietal region, whilst no significant consistency was evident with the CPM. Of the three groups the consistent effects were strongest in the BPF.

Overall, the observed effects were stronger in the BPF (T = 7.9, d.f. = 7, 1, p < .001) than the BPM (T = 4.2, d.f. = 7, 1, p < .005) and CPM (T = 3.7, d.f. = 7, 1, p < .01)

### 5.4.4 Worst Performance Groups and the MRT

To examine whether level of spatial ability is a factor that needs to be taken into account when investigating intra-gender effects, the analysis of lower level spatial ability (Worst Performance) groups (8 subjects) are presented as a means of comparison with the higher spatial ability groups.

**Pointmaps of Baseline Task**

The pointmaps in the left hand column in Figure 5.6, illustrating the SSVEP magnitude from the Visual Vigilance task, were from the Worst
Figure 5.6 The topographic maps are from the Worst Performance Males (WPM), Worst Performance Females (WPF) and Best Performance All (BPA) groups. Column 1 illustrates the distribution of the SSVEP magnitude during the Visual Vigilance (Baseline) task. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 2 illustrates the equivalent distribution during the MRT with Column 3 illustrating the distribution of the SSVEP phase during the MRT referenced to the Visual Vigilance task phase.
Performance Male (WPM) and Female (WPF) groups, as well as the Best Performance All (BPA) group. The results of the BPA group is presented, but the results of the BPA group will not be considered in the Discussion (Chapter 6).

The topography of the three pointmaps is similar in that the maximum SSVEP magnitude occurs in the occipital/parietal region in all three pointmaps, although the SSVEP magnitude is also quite large in the centro/frontal region of the BPA group. The occipito/parietal effect was more pronounced in the WPM and WPF than the BPA, with a slight LH lateralization in SSVEP magnitude in the occipito/parietal region in the WPM and WPF. A weak LH lateralization effect was found in the frontal and temporol/parietal regions of the BPA group, where the left frontal and left temporol/parietal regions showed a larger SSVEP magnitude than the right frontal and right temporol/parietal regions.

Pointmaps of Mental Rotations Test

The pointmaps in the centre column in Figure 5.6, illustrating the SSVEP magnitude from the MRT, were from the WPM, WPF and BPA groups. The SSVEP magnitude in the occipital/parietal region of the WPM, WPF and BPA groups was much larger than in any of the other regions. Some LH laterality effect was observed in all three groups, but was most significant in the WPM, where the SSVEP magnitude was more pronounced in the left occipital/parietal region than in the right occipital/parietal region. The MRT SSVEP phase pointmaps shown in the right hand column will be described in the difference maps section as the SSVEP phase difference maps.

Difference Maps

The difference maps of SSVEP magnitude and SSVEP phase shown in the left and centre column respectively of Figure 5.7 are the MRT task, of the WPM, WPF and BPA groups, subtracted from their respective Baseline task.

The topography of the WPM group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the frontal region, as well as a weak effect in the occipital/parietal region. There was a weak RH lateralization effect in SSVEP magnitude reduction in the occipital/parietal region. However, no noticeable lateralization effect in terms of
Figure 5.7  The topographic maps are from the Worst Performance Males (WPM), Worst Performance Females (WPF) and Best Performance All (BPA) groups. The Maps illustrate the difference in the SSVEP associated with the Visual Vigilance (Baseline) and MRT tasks. Column 1 indicates the magnitude differences. Column 2 indicates the phase differences, while Column 3 illustrates the distribution of the square root of Hotelling’s $T^2$ (T) based on paired comparison between the two tasks. The Iso-T values illustrated correspond to single comparison p values of 1 %, 0.5 % and 0.1 %.
SSVEP magnitude reduction was evident. The parietal region displayed a noticeable LH lateralization in SSVEP magnitude increase.

The topography of the WPF group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in all areas save the centro/parietal and prefrontal regions. Overall no pronounced laterality effect was evident.

The topography of the BPA group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in all areas save the centroparietal and occipital regions. A weak RH lateralization in SSVEP magnitude reduction was observed in the temporo/parietal region. A significant SSVEP magnitude increase was evident in the occipital and centro/parietal regions.

In examining the SSVEP phase difference maps the WPM demonstrated the most significant phase lag, with the largest phase lag in the left temporo-parietal region. The WPF demonstrated the largest phase lag in the right temporo-parietal region, whilst the BPA demonstrated the largest phase lag in both the right and left temporo-parietal regions and left frontal region. The WPM showed a noticeable phase advance in the frontal region, particularly in the prefrontal region. The WPF showed the most noticeable phase advance in the left temporo-parietal region and frontal region. No significant phase advance was observed in the BPA.

**Hotelling's T Probability Maps**

The Hotelling's T probability maps illustrated in the right hand column of Figure 5.7 are the MRT task, of the WPM, WPF and BPA groups, compared with their respective Baseline task. The topography of the probability maps indicates that the most consistent effects were in the frontal and temporo-parietal regions for the WPF. In the WPM the most consistent effects were observed in the frontal and left temporo-parietal regions, whilst no significant consistency was evident with the BPA group save a small area in the right temporo-parietal region. Of the three groups the consistent effects were strongest in the WPF.

Overall, the observed effects were stronger in the WPF ($T = 9.7$, d.f. = 7, 1, $p < .001$) than the WPM ($T = 5.2$, d.f. = 7, 1, $p < .005$) and BPA ($T = 4.4$, d.f. = 7, 1, $p < .005$).
CHAPTER 6

DISCUSSION
6.1 DISCUSSION

The discussion is divided into five sections. Section 6.1.1 investigates hemispheric specialisation for mental rotation in the All group. The All group consisted of all 41 subjects in the SSVEP Population analysed as a combined group. In Section 6.1.2 the subjects from the All group were divided into male and female groups (20 males, 21 females) to investigate whether there were any specific effects due to gender. Performance level and hemispheric specialisation for mental rotation was investigated in sub-groups (8 subjects) of the SSVEP Population in Section 6.1.3. Gender effects in behavioural performance were investigated in Section 6.1.4. The summary and conclusion is located in Section 6.1.5.

6.1.1 Hemispheric Specialisation in the All group

A role for both hemispheres during the performance of the Mental Rotations Test (MRT) was found in the All group in this study. As mentioned above, the All group consisted of all 41 subjects in the SSVEP Population analysed as a combined group. No noticeable lateralization effect was evident, although there was a very weak left hemisphere (LH) lateralization in activation. With respect to the visual vigilance Baseline task of the SSVEP Population, the MRT task displayed a reduction in SSVEP (Steady State Visually Evoked Potential) magnitude in both hemispheres. From the difference map (Figure 5.3) it can be seen that there was a noticeable reduction in SSVEP magnitude, with respect to the Baseline task, in the occipito/parietal and frontal regions.

When examining the SSVEP phase, no significant hemispheric difference in phase distribution was evident between the LH and right hemisphere (RH). The Hotelling's T probability map (Figure 5.3) showed that consistent effects were evident in all areas save centro/parietal and occipital regions. Gender differences will be discussed in Section 6.1.2.

To relate the SSVEP magnitude data to cognitive processes of the brain, the probe evoked potentials (EPS) method is used (Papanicolaou and Johnstone, 1984), as discussed in Chapter 3. If a regional decrease in SSVEP magnitude is interpreted as indicating increased cognitive activity in the region, then the finding of this study suggests a role for both hemispheres in the performance of mental rotation.
A Role for Both Hemispheres in Mental Rotation

The finding of bilateral cerebral activation for mental rotation is in agreement with the EEG study by Gevins et al (1979). However, it does not conform with the general view that the right hemisphere is dominant in visual-spatial processing (Bryden, 1988), which is also supported by many electrophysiological studies (see Literature Review).

A bilateral activation for mental rotation does not agree with the findings of the EEG alpha study by Ornstein et al (1980), nor that of other non-electrophysiological studies (e.g. Mehta and Newcombe, 1991; Mehta, Newcombe and Damasio, 1987; Fischer and Pellegrino, 1988; Corballis and Sergent, 1989), which reported a LH lateralization for mental rotation.

The MRT used in this study was very similar to the mental rotation task used in the study by Ornstein et al (1980), who found a LH lateralization for EEG alpha in the mental rotation task, interpreted as indicating greater LH activation than RH activation for mental rotation. Ornstein et al also found that other visual-spatial tasks were RH lateralized, and suggested that mental rotation may utilize a different processing strategy than that of other visual-spatial tasks. They went on to suggest a hypothesis that mental rotation may elicit a more analytic processing strategy, which may be more of a LH capacity than a RH capacity, and that other more simple visual-spatial tasks may elicit a more synthetic processing strategy, which may be more of a RH capacity than a LH capacity. Such a hypothesis, however, does not easily account for studies that have indicated a superior role for the right hemisphere in mental rotation (e.g. Deutsch et al, 1988; Ditunno and Mann, 1990; Papanicolaou et al, 1987, Corballis and Manalo, 1993).

However, it is possible that the strategy used in mental rotation varies, depending on the individual. If using a LH processing strategy is related to a superior performance on the MRT, then one might hope to see evidence of a greater LH activation then RH activation in subjects whose behavioural performance were best. This is investigated in Section 6.1.3.

Differential Processing

In this study mental rotation was most noticeably associated with SSVEP magnitude reductions in the frontal and occipito/parietal regions. This suggests the cortical involvement of different regions during the MRT. Temporal
information has not yet been investigated, and it is possible that this may indicate differential cerebral processing associated with this task. Specific sequences of activation, using high temporal resolution analysis, has been reported in the Wisconsin Card Sort task (Silberstein, Ciorciari and Pipingas, 1992).

The SSVEP magnitude reduction observed in the occipito/parietal region has been reported in other studies using different tasks (Silberstein et al, 1990). It is unlikely that the cerebral processing in this region is specialised or peculiar to mental rotation, though it may still be consistent with the suggestion that this region may be involved in visual-spatial processing.

Centro/Parietal Region

This study found that the centro/parietal region exhibited a slight decrease in activation during the MRT with respect to the Baseline task. The parietal region is thought to be involved in the cognitive processes associated with visual-spatial tasks, and evidence for the involvement of the centrolparietal region during mental rotation has been previously reported in a SSVEP study (Wilson and O'Donnell, 1986) in which only SSVEP latency was investigated.

There is evidence that the parietal cortex is involved in visual-spatial attention (Petersen, Robinson and Currie, 1989). Hence, it is possible that the centro/parietal region was activated in the visual vigilance Baseline task due to cerebral processes engaged during visual-spatial attention. The slight increase in SSVEP magnitude in the centro/parietal region of the MRT with respect to the Baseline task (i.e. decrease in activation) may have arisen because the Baseline task activated this region more than the MRT.

Confounding Factors

There are many factors that independently, or in combination, may contribute to the discrepancies observed between different studies. Some of these include: spatial resolution of measurements; sex differences in lateralization (Voyer and Bryden, 1990; Trotman and Hammond, 1979, Tucker, 1976); direction of figure rotation (Burton et al, 1992); differences in spatial abilities of subjects (Ray et al, 1981; Voyer and Bryden, 1990); familiarity of subject with stimuli (Voyer and Bryden, 1990); subjects adopting different strategies when solving the task (Furst, 1976); results misleading due to artifacts contaminating
data (Barlow, 1986); flaw in methodology, analysis procedure or interpretation of data. The size of the population studied needs also to be taken into account when comparing different studies, especially if there is considerable individual variation. The population of 20 males and 21 females (41 subjects total) in this study compares well with other studies in size.

This study has attempted to control for a number of confounding factors. The spatial resolution used (64 electrodes) is better than any previous known electrophysiological study dealing with mental rotation. Recordings from the more lateral areas of the scalp were therefore included, which most of the mental rotation electrophysiological studies have not examined.

The subjects were divided into male and female groups to investigate whether there were any specific effects due to gender. These groups were further divided into sub-groups according to their spatial ability, allowing the effect of differences in the level of spatial ability to be examined (see Section 6.1.3).

6.1.2 Sex Differences in Lateralization

The mental rotation EEG alpha study by Ornstein et al (1980) found no significant sex differences in hemispheric lateralization. The finding in this study, from examining the SSVEP magnitude, suggests no lateralization for mental rotation in both the males and the females.

The frontal regions in both males and females were activated, with the effect being stronger in the females. The temporolparietal regions in the males showed no evidence of significant activation for mental rotation, in contrast to the females, who displayed a noticeable activation in these regions. The Hotelling's T showed that activation of the temporoparietal and frontal regions were more consistent in the females than the males. The centrolparietal regions in both the males and females showed no evidence of activation during mental rotation, indeed in the males there was a noticeable decrease in activation in this region.

The SSVEP magnitude data suggests that both males and females showed bilaterally activation for mental rotation, but differences in the pattern of activation were evident. But for the occipitolparietal region, in the males the MRT appeared to increase the activation only in the frontal region. In the females the activation was observed to increase globally save the centrolparietal and prefrontal regions. This suggests that cortical processing associated with mental rotation may be more localized in the males than the females. This is consistent
with the suggestion that males and females may use different strategies when performing mental rotation (Allen and Hogeland, 1978). It is also consistent with the suggestion that there is a neuroanatomical difference in the structure, organization and/or function of the brain between males and females (see Section 2.2.3 in Literature Review).

Changes in phase also showed specific effects. There was evidence of a gender difference in the temporolparietal phase distribution. With respect to the SSVEP phase the males demonstrated the largest phase lag (increased latency) in the left temporolparietal region, whereas females demonstrated the largest phase lag in the right temporolparietal region. The temporol/parietal phase distribution suggests sex differences in the pattern of cortical activation associated with the MRT, but such a interpretation must be treated with caution because of the uncertainty as to the basis of these changes.

Significant spatial ability by visual field interaction is known to occur (Voyer and Bryden, 1990). In the next section the higher spatial ability (Best Performance) group from both males and females are compared to examine for gender effects. These higher spatial ability groups are also compared with lower spatial ability (Worst Performance) groups to investigate whether there are intra-gender effects between groups of different levels of spatial ability.

### 6.1.3 Performance Level and Hemispheric Specialisation

By examination of the SSVEP topographic data in the different performance groups, it is possible to investigate whether the SSVEP topography differs for subject groups with different levels of performance on the MRT.

In the visual vigilance Baseline task, there was a RH lateralization in SSVEP magnitude reduction in the temporolparietal region in the Best Performance Females (BPF) group (Figure 5.5). In the Worst Performance Females (WPF) group (Figure 5.7) no noticeable lateralization effect was evident. The Hotelling's T probability maps of the BPF group (Figure 5.5) and WPF group (Figure 5.7) showed consistent effects in the frontal and right temporolparietal regions for the BPF group, and in the frontal and temporolparietal regions for the WPF group.

These results suggest that the performance level of the females during mental rotation may affect the hemispheric lateralization for mental rotation. For females, a RH lateralization appears to be associated with higher spatial ability.
There were also some significant differences in the hemispheric activation pattern between the Best Performance Males (BPM) group (Figure 5.5) and the Worst Performance Males (WPM) group (Figure 5.7). With respect to the visual vigilance Baseline task, there was a noticeable LH lateralization in SSVEP magnitude reduction in the BPM group in the temporoparietal region. The WPM group showed no noticeable lateralization effect in terms of SSVEP magnitude reduction. There was very little activation evident in the WPM group. The Hotelling's T probability maps show that the effects were most consistent in the left temporoparietal region for the BPM group (Figure 5.5) and frontal and left temporoparietal regions for the WPM group.

These results suggest that the performance level of the males during mental rotation may also influence the hemispheric lateralization for mental rotation. A LH lateralization appears to be associated with higher spatial ability for the males.

Whilst LH processing seems to be more superior than RH processing for mental rotation in the males, RH processing appears to be more superior than LH processing for mental rotation in the females. A Compatible Performance Males (CPM) group with respect to the BPF group was analysed in order to investigate the possibility that the observed sex differences in SSVEP topography between the higher spatial ability groups (BPF and BPM) could be due to differences in the level of performance per se. The CPM group was selected so that behavioural scores matched the BPF. No significant lateralization effect in SSVEP magnitude was found in the CPM group, with very little activation being evident, and no consistent effect was evident in the Hotelling's T map. The BPF showed consistent effects in the Hotelling's T, a RH lateralization in SSVEP magnitude reduction, as well as evidence of widespread activation. Hence, from comparison of the BPF and CPM groups, performance per se does not appear to account for the gender differences in hemispheric lateralization observed between the higher spatial ability groups.

It has been suggested by Ornstein et al (1980) that mental rotation may elicit a more analytic processing strategy, which in turn may be more of a LH capacity than a RH capacity. Within the framework of this hypothesis the observations of this study may be interpreted as suggesting that 'the higher spatial ability males may use an analytic strategy, with a predominantly LH capacity, in solving the task, whereas the lower spatial ability males may use some other visual-spatial processing strategy in solving the task. With the Worst Performance
groups there is uncertainty as to whether some subjects made a serious attempt at performing the task. With the Best Performance groups the behavioural scores indicate that the subjects did make a serious attempt at performing the task.

It is more difficult, however, to explain why the higher spatial ability females showed a RH lateralization for mental rotation. A possible, but speculative explanation within the framework of the hypothesis by Ornstein et al, is that females may be more adept when using a synthetic strategy, with a predominantly RH capacity, to perform mental rotation. Higher spatial ability females may use a synthetic strategy, with a predominantly RH capacity, in solving the task, whereas the lower spatial ability females may use some other visual-processing strategy in solving the task. Evidence suggesting that differences in performance level of females is related to differences in the strategies of mental rotation employed has been previously reported (Kail, Carter and Pellegrino, 1979).

If, however, both high spatial ability males and females use the same type of strategy in solving the task, then the findings from this study are difficult to interpret unless there are biological gender differences in the function of the brain (see Section 2.2.3). This experiment was not designed to test the type of strategy employed during mental rotation, so the question of strategy differences can not be answered. However, if there was a sex difference in strategies employed then it still needs to be explained why such a sex difference in strategy choice for optimum performance exists. No satisfactory explanation is presently available, except perhaps the simplest interpretation, again that of biological gender differences in brain function.

The lateralization effect was not as strong in the BPF as in the BPM. The finding of greater hemispheric lateralization for males than females is reported by many studies (McGlone, 1980), although some consider that "the data provide only very weak support" for this notion (Bryden, 1988, p.156).

An important conclusion from this study is that when examining for hemispheric lateralization effects in mental rotation, not only do gender effects need to be considered, but also the level of spatial ability in the comparison groups.

The report of other studies having found a spatial ability by laterality effect (Ray et al, 1981; Voyer and Bryden, 1990), although not necessarily in concordance with the nature of the laterality effect found in this study, do indicate
that level of spatial ability is an important variable that needs to be considered in studies on hemispheric lateralization.

6.1.4 Gender Effects in Behavioural Performance

The finding of a male superiority in the performance of the MRT, for both the Total Population (Table 5.1) and the SSVEP Population (Table 5.2), is consistent with most studies done on the Shepard/Metzler mental rotations test developed by Vandenberg and Kuse (1978) (Goldstein, Haldane and Mitchell, 1990). Since the behavioural results of the Total Population and the SSVEP Population were similar, and the SSVEP Population is more relevant in the context of this thesis, only the background of the SSVEP Population will be discussed.

The mean age and education level of the males in the SSVEP Population was greater than the females, but the difference was not significant. Hence, this is unlikely to be the source of the difference in behavioural performance. The male group had a greater proportion of students with a Science background, as opposed to Arts, than the female group. This may have contributed to the male superior behavioural performance if it is assumed that subjects studying Science generally tend to have better spatial abilities than subjects who study Arts (Kalichman, 1986). However, it is unlikely that this could account for the large difference in behavioural performance found in this study, as the difference in proportion between male and female Science students was minor. The difference then, most likely represents a genuine sex difference in the performance of a visual-spatial task.

Whilst the MRT used in the SSVEP Population was timed, the MRT used in the Preliminary Study was untimed and therefore scored differently. In the Preliminary Study there was no significant difference in the mean scores between the male and female groups (see Table 5.3). Within the constraints imposed by the small population used in the Preliminary Study (8 males, 8 females) the finding that a significant male advantage is found only in conditions with strict time limits is similar to that found by Goldstein, Haldane and Mitchell (1990). When presented under untimed conditions the average response rate per item for the MRT was found not to be significantly different between males and females in the Preliminary Study.
A significant difference, showing a superior male performance, was also evident on the line orientation task (LOT), which is consistent with other studies (Benton, Varney and Hamsher, 1978).

6.1.5 Summary and Conclusion

A main finding of this study was that when all 41 subjects were considered as one group, no noticeable lateralization in cerebral activation associated with mental rotation was evident.

A possible gender difference in SSVEP activation associated with mental rotation was found, when analyzing the 20 male and 21 female subjects as two separate groups, consistent with the suggestion that the cortical processing associated with mental rotation may be more localized bilaterally in the males than the females. However, no noticeable lateralization effects for mental rotation were found in the males or females, and hence no gender differences in hemispheric lateralization was evident.

More specific effects were found when the SSVEP phase was considered. The temporo/parietal phase distribution suggested sex differences in the pattern of cortical activation associated with the MRT. Interpretation of these results must be treated with caution because of the uncertainty as to the basis of these phase changes.

There were observed gender differences in hemispheric lateralization in the higher spatial ability subjects. A LH lateralization for mental rotation was associated with better behavioural performance on the task for the males. The Best Performance Female group showed the opposite effect, where a RH lateralization was associated with better performance on the task. The lateralization effect appeared to be stronger in the Best Performance Males than the Best Performance Females. The finding of a spatial ability by laterality effect has been previously reported on a paper folding visuospatial task (Ray et al, 1981), as well as a mental rotation task (Voyer and Bryden, 1990). Although these studies do not necessarily concord on the nature of the laterality effect found, they do indicate that level of spatial ability is an important variable that needs to be considered in studies on hemispheric lateralization.

Evidence suggesting a role for the parietal cortex in visual-spatial attention was also found. On performance alone the males performed significantly better on
the mental rotations test, a finding that is in agreement with many other studies (Goldstein, Haldane and Mitchell, 1990).

An important conclusion from this study is that when examining for hemispheric lateralization effects in mental rotation, not only does gender effects need to be considered, but also the level of spatial ability in the comparison groups. Failure to do this may partly explain some of the contradictory findings in the literature. This study was not specifically designed to select subjects with high and low spatial ability, and did not attempt to quantify strategies. A future SSVEP study aimed at replicating the results, by investigating spatial ability specifically, would be of value. Such a study might also investigate what type of strategies are employed by the subjects.
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APPENDICES
7.1 APPENDIX

GLOSSARY

Baseline Task: See Section 4.3.1.

Best Performance All: See Section 5.3.3.

Best Performance Females: See Section 5.3.3.

Best Performance Groups: See Section 5.3.3.

Best Performance Males: See Section 5.3.3.

BPA: Best Performance Males. See Section 5.3.3.

BPF: Best Performance Females. See Section 5.3.3.

BPM: Best Performance Males. See Section 5.3.3.

Compatible Performance Males: See Section 5.3.3.

CPM: Compatible Performance Males. See Section 5.3.3.

Difference Map: See section 4.4.3.

Education level: See Section 4.1.

Education background: See Section 4.4.

EFT: Embedded Figures Task. See Section 7.4.

Embedded Figures Task: See Section 7.4.

Hotelling's T Probability Map: See Section 4.4.3 and Section 4.5.2.
**Line Orientation Task:** See Section 4.3.3.

LOT: Line Orientation Task. See Section 4.3.3.

**Mental Rotations Test:** See Section 4.3.2.

MRT: Mental Rotations Test. See Section 4.3.2.

**Normalizing:** See Section 4.4.2.

**No Stimulation/Stimulation task:** See Section 4.3.1.

NS/STIM task: No Stimulation/Stimulation. See Section 4.3.1.

**Numbers Tasks:** See Section 4.3.1.

**Pointmap:** See Section 4.4.3.

**Preliminary Study:** See Section 4.6.

**Probability Map:** See Section 4.4.3 and Section 4.5.2.

**Rlock data:** See Section 4.4.1

**Rmagp data:** See Section 4.4.

SCAN: Swinburne Centre for Applied Neurosciences.

SSPT: Steady State Probe Topography. See Section 3.1.


SSVEP Population: See Section 4.1.

**Steady State Probe Topography:** See Section 3.1
Steady State Visually Evoked Potential: See Section 3.1.

Total Population: See Section 4.1.

Window: See Section 4.4.1.

Worst Performance Females: See Section 5.3.3.

Worst Performance Groups: See Section 5.3.3.

Worst Performance Males: See Section 5.3.3.

WPF: Worst Performance Females. See Section 5.3.3.

WPM: Worst Performance Males. See Section 5.3.3.
7.2 APPENDIX

Reading Task

The Reading Task, as the name implies, involved reading text that was displayed on the screen. The text was taken from a publication by the Australian Science and Technology Council (Australia. Australian Science and Technology Council, 1991, p.1-2).

The reading task consisted of Part 1 (practice) and Part 2 (recording). Two text screens, each being displayed for about 90 seconds, were shown in each part. When the first text screen was displayed the subject would read silently or aloud (depending on the order) for about 90 seconds. The second screen would then replace the first text screen, and the subject would then read the opposite of what they read on the first text screen. On the top of the screen was written either read silent or read aloud as a reminder to the subject. This task was looking at the differences between reading silent and reading aloud. Half the subjects of each sex in the SSVEP Population would read aloud first and half would read silent first, so as to minimize any order effects. Because there was 21 suitable female recordings it wasn't possible to get exactly half of each for the females. The subjects were asked to read at their own comfortable pace, and when reading aloud, at their normal talking voice level. They were also informed that it didn't matter if they didn't finish reading all the text, but if they did, then they were asked to press any button on the multiple button response box, which would allow the time they finished reading to be recorded. After they had pressed the button they were instructed to start reading from the top again.

Because of the small size of the text at the normal distance of 134 cm it was necessary to move the task monitor screen closer to the subject, as few subjects were comfortable at reading from this distance. The maximum letter size on the screen was 0.4 cm horizontally and 0.55 cm vertically, subtending an angle of 10' 16" horizontally and 14' 07" vertically to the subject from the normal distance of 134 cm. Two other positions were used. The first reading position was at an approximate distance of 110 cm from the screen, subtending an angle of 12' 30" horizontally and 17' 07" vertically to the subject. The second reading distance was at an approximate distance of 81 cm from the screen, subtending an angle of 16' 59" horizontally and 23' 21" vertically to the subject. The maximum luminance measured from the text screen was 10.2 Cd/m².
7.3 APPENDIX

Verbal Aptitude Test (VAT)

The VAT test used in this study was designed by the author. It involved presenting a word on top of the monitor screen, and then underneath this word presenting four other words (see Figure 7.1). The subject had to decide whether all the four bottom words were similar in meaning to the single word on top of the screen. All words were adjectives, and at the most, only one word out of the four would be incorrect.

There was 16 problems presented in Part 1 and 14 problems presented in Part 2. In the actual recording 13 text screens would appear in the first 3 minutes, with screen duration lasting from about 8 to 16 seconds in the recording period. The time allowed for the subject to do each problem was based on the results of a preliminary behavioural study (see Section 4.6). The criteria used being the time in which 81.25% of the subjects (the 13 fastest subjects) had responded. This same criteria was used in the EFT task. The text screens were made by using the Graphics Editor in the Show Partner software.

The maximum size of the letters on the text screen was 1.35 cm horizontally and 1.1 cm vertically, which subtended an angle of 34° 38" horizontally and 28° 13" vertically to the subject. The maximum luminance was 14.0 Cd/m².

INTELLECTUAL

ACADEMIC

LEARNED

SCHOLASTIC

INEPT

Figure 7.1 This is an example of a VAT problem. Note that since the word "INEPT" does not have a similar meaning to the word "INTELLECTUAL" the correct answer would be NO.
7.4 APPENDIX

Embedded Figures Task (EFT)

In the EFT the subject had to identify a given simple figure on the left of the screen which was camouflaged, embedded or hidden in a more complex figure to the right of the screen. See Figure 7.2 for an example. The figures used were not based on any one particular EFT, but rather a variety of different types of figures from various EFT were used in the experiment. In the 3 minute recording 13 different EFT figure screens appeared, the subject having between about 6 to 18 seconds in which to make a response, depending on the difficulty of the problem. In all, 15 figures were each presented in both Part 1 and Part 2 of the EFT.

The largest of any single object presented during the recording phase of the EFT was approximately 10 cm x 10 cm, hence subtending an angle of $9^\circ 7' 51''$ horizontally and vertically to the subject. One of the smallest figures was approximately 4.5 cm horizontally and 4.3 cm vertically on the screen. Of the 13 different EFT figure screens appearing during the actual recording the maximum luminance was 33.0 Cd/m$^2$, but in 12 of these figure screens the luminance did not exceed 19.0 Cd/m$^2$.

Figure 7.2 This is an example of a EFT problem. The object on the left is hidden in the more complex figure to the right.
7.5 APPENDIX

EMBEDDED FIGURES TASK (EFT) RESULTS

BEHAVIOURAL RESULTS

This section presents the results of the statistical analysis of the Embedded Figures Task (EFT) behavioural data from the Total Population, SSVEP Population and Preliminary Study. Also presented is the scores from the different Performance Groups.

Total Population

The results are summarised in Table 7.1. The mean score for the males on the Embedded Figures Task (EFT) was 79.87 % (S.Dev. = 12.80) whereas the mean score for the females on the EFT was 72.17 % (S.Dev. = 15.70). No significant difference was found with the EFT when comparing the means of the male and female groups (t = 1.872, d.f. = 50, p > .05). There was no significant difference between the two standard deviations (ANOVA: F = 1.504, d.f. = 25, 25, p > .05).

SSVEP Population

A summary of the results can be found in Table 7.2. The mean score for the males on the EFT was 79.17 % (S.Dev. = 13.87) compared to a mean score for the females on the EFT of 70.17 % (S.Dev. = 15.63). There was no significant difference between the means of the male and female groups on the EFT (t = 1.863, d.f. = 39, p > .05), and also no significant difference between the two standard deviations (F = 1.271, d.f. = 20, 19, p > .05).

Performance Groups Scores

The subjects in the SSVEP Population were also divided into Performance groups, based on their performance during Part 2 of the EFT. The performance at the time of the actual recording was used for all the subjects in the Performance groups. The Performance Groups consisted of Best Performance Males (BPM).
Table 7.1 Tabulation of the results of the behavioural scores from the Total Population. There was no significant difference in performance on the EFT between males and females.

Table 7.2 Tabulation of the results of the behavioural scores from the SSVEP Population. There was no significant difference in performance on the EFT between males and females.
Best Performance Females (BPF), Worst Performance Males (WPM) and Worst Performance Females (WPF). All Performance Groups consisted of 8 subjects each. Subjects excluded were either borderline between the Best and Worst Performance group or their exact scores were unavailable.

A Compatible Performance Males (CPM) group was also constructed. Eight males were chosen so that their scores matched the BPF group, therefore the scores of the CPM group had a similar distribution to that of the BPF group. Furthermore a Best Performance All (BPA) group was also constructed, consisting of the 8 subjects with the best performance regardless of sex. The EFT BPA group consisted of 5 males and 3 females.

The scores (in %) of the various Performance Groups on Part 2 of the EFT was as follows: Best Performance Males (mean = 92.5 %, S.Dev. = 5.2); Best Performance Females (mean = 87.5 %, S.Dev. = 5.2); Worst Performance Males (mean = 66.7 %, S.Dev. = 12.5); Worst Performance Females (mean = 64.2 %, S.Dev. = 10.5); Compatible Performance Males (mean = 87.5 %, S.Dev. = 5.2); Best Performance All (mean = 95.0 %, S.Dev. = 2.9).

The subjects used for the EFT performance groups were not necessarily the same as the subjects used for the MRT performance groups, although some subjects were included in both groups depending on their scores.

Preliminary Study

The results are summarised in Table 7.3. The mean score for the males on the EFT was 92.13 % (S.Dev. = 3.30) compared to a mean score for the females on the EFT of 88.00 % (S.Dev. = 6.95). There was no significant difference between the mean scores of the male and female groups on the EFT (t = 1.419, d.f. = 14, p > .05), but there was a significant difference between the two standard deviations (ANOVA: F = 4.435, d.f. = 7, 7, p < .05).

The mean total task time for the males on the EFT was 624.553 sec (S.Dev. = 229.368) compared to the mean total task time for the females on the EFT of 673.802 sec (S.Dev. = 188.343). There was no significant differences on the mean total task times between the male and female groups on the EFT (t = .466, d.f. = 14, p > .05), and also no significant difference between the two standard deviations (ANOVA: F = 1.483, d.f. = 7, 7, p > .05).

The mean average response rate per item for the males on the EFT was 6.246 sec (S.Dev. = 6.058) compared to the mean average response rate per item
Table 7.3 Tabulation of the results from the EFT of the behavioural scores, total task times and average response rate per item from the Preliminary Study. There was no significant difference in performance between the males and females, but the variance between the male and female scores was significantly different. No significant difference in the total task times between the male and female groups was found. No significant difference in the mean average response rate per item between the male and female groups was found.
for the females on the EFT of 6.738 sec (S.Dev. = 6.086). There was no significant differences on the mean average response rate per item between the male and female groups on the EFT (t = 1.619, d.f. = 1598, p > .05), and also no significant difference between the two standard deviations (ANOVA: F = 1.010, d.f. = 799, 799, p > .05).

**SSVEP TOPOGRAPHIC DATA**

The analysis of the EFT is similar to that of the MRT (see Section 5.4).

**SSVEP Population and Embedded Figures**

**Pointmaps of Visual Vigilance Task**

The pointmaps in the left hand column in Figure 7.3 illustrate the SSVEP magnitude from the Visual Vigilance task (Baseline task) of the Males, Females and All of the SSVEP population. These pointmaps are identical to the Visual Vigilance task pointmaps described in Section 5.4.2, but are described again here for consistency.

The topography of the three pointmaps is similar in that the maximum SSVEP magnitude occurred in the occipitalparietal region in all three pointmaps. The effect was larger in the Females than the Males. With the Females and All group this effect was more pronounced in the left occipitalparietal region than the right occipitalparietal region, whereas no significant laterality effect in this region was found in the Males.

**Pointmaps of Embedded Figures Task**

The pointmaps in the centre column of Figure 7.3 illustrate the SSVEP magnitude from the EFT of the Males, Females and All of the SSVEP population. The SSVEP magnitude in the occipitalparietal region of all three groups was much larger than in any of the other regions. No significant laterality effect in the occipito/parietal region was found in the Male and All groups, but a LH lateralization was evident in the Females.

Because the EFT SSVEP phase pointmaps are the negative of the SSVEP phase difference maps, due to the normalization procedure, the EFT SSVEP...
Figure 7.3 The topographic maps are from the Males, Females and All groups of the SSVEP Population. Column 1 illustrates the distribution of the SSVEP magnitude during the Visual Vigilance (Baseline) task. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 2 illustrates the equivalent distribution during the EFT with, Column 3 illustrating the distribution of the SSVEP phase during the EFT referenced to the Visual Vigilance task phase.
phase pointmaps shown in the right hand column will be described in the difference maps section, as SSVEP phase difference maps, to avoid repetition. This deferral will apply to all subsequent descriptions involving EFT SSVEP phase pointmaps.

**Difference Maps**

The difference maps of SSVEP magnitude and SSVEP phase shown in the left and centre column respectively of Figure 7.4 are the EFT task, of the Males, Females and All of the SSVEP Population, subtracted from their respective Baseline task (Visual Vigilance task). To examine the effects of the EFT task with respect to the Baseline task, the MRT pointmap was subtracted from the Baseline pointmap.

The topography of the All group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the occipito/parietal and left temporolparietal regions, as well as weak effects in the frontal and left temporal regions. There was a very weak LH lateralization effect in SSVEP magnitude reduction in the frontal and temporolparietal regions. The centralparietal region showed a significant SSVEP magnitude increase.

The topography of the Male group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the occipitolparietal, left temporolparietal and frontal regions. A LH lateralization in SSVEP magnitude reduction was evident in the in the occipitolparietal region, as well as a weak LH lateralization in the temporolparietal region. The centralparietal region showed a significant SSVEP magnitude increase, particularly the right centralparietal region.

The topography of the Female group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the occipitolparietal and left temporolparietal regions. There was a very weak LH lateralization effect in SSVEP magnitude reduction in the temporoparietal region. There was also a noticeable SSVEP magnitude increase in the centralparietal region.

With the SSVEP phase difference maps the Males demonstrated the largest phase lag in the left temporolparietal, right temporal regions, whilst the Females demonstrated the largest phase lag in the right temporolparietal region. The All group demonstrated the largest phase lag in the right temporolparietal region. In
Figure 7.4 The topographic maps are from the Males, Females and All groups of the SSVEP Population. The Maps illustrate the difference in the SSVEP associated with the Visual Vigilance (Baseline) and EFT tasks. Column 1 indicates the magnitude differences. Column 2 indicates the phase differences, while Column 3 illustrates the distribution of the square root of Hotelling's $T^2$ ($T$) based on paired comparison between the two tasks. The Iso-T values illustrated correspond to single comparison $p$ values of 1 %, 0.5 % and 0.1 %.
the Females the frontal region showed a significant phase advance, whilst no significant phase advance was evident in the Males. The All group displayed a significant phase advance in the frontal region.

**Hotelling’s T Probability Maps**

The Hotelling’s T probability maps illustrated in the right hand column of Figure 7.4 are the EFT task, of the Males, Females and All of the SSVEP population, compared with their respective Baseline task. The topography of the probability maps indicate that the most consistent effects were in the frontal regions for all three groups. In the prefrontal region and left temporal region the Males showed greater consistency than the Females. All three groups showed a significant lack of consistency in the occipital and parietal regions.

Overall, the observed effects were about equal for the Females (T = 7.5, d.f. = 19, 1, p < .001) and the Males (T = 7.6, d.f. = 19, 1, p < .001). The effect in the 41 subject All group was conservatively estimated with respect to the Male and Female groups, as the degrees of freedom used for the F-distribution value was the same as that used for the 20 subject Male group (T = 8.8, d.f. = 19, 1, p < .001).

**Best Performance Groups and the EFT**

**Pointmaps of Visual Vigilance Task**

The pointmaps in the left hand column in Figure 7.5, illustrating the SSVEP magnitude from the Visual Vigilance task, were from the Best Performance Male (BPM) and Female (BPF) groups, as well as the Compatible Performance Males (CPM) group with respect to the BPF group (see Section 5.3.3).

The topography of the three pointmaps was similar in that the maximum SSVEP magnitude occurred in the occipito/parietal region in all three pointmaps, although the SSVEP magnitude was also quite large in the centro/frontal region in all three groups. The occipitoparietal SSVEP magnitude was more pronounced in the BPF than the BPM and CPM. The BPM and CPM showed a slightly larger SSVEP magnitude in the left temporo/parietal region than the right
Figure 7.5  The topographic maps are from the Best Performance Males (BPM), Best Performance Females (BPF) and Compatible Performance Males (CPM) groups. Column 1 illustrates the distribution of the SSVEP magnitude during the Visual Vigilance (Baseline) task. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 2 illustrates the equivalent distribution during the EFT with Column 3 illustrating the distribution of the SSVEP phase during the EFT referenced to the Visual Vigilance task phase.
temporolparietal region, whereas the BPF showed a larger SSVEP magnitude in the right temporolparietal region than the left temporolparietal region.

**Pointmaps of Embedded Figures Task**

The pointmaps in the centre column in Figure 7.5, illustrating the SSVEP magnitude from the EFT, were from the BPM, BPF and CPM groups. The SSVEP magnitude in the occipitolparietal region of the BPM, BPF and CPM groups was much larger than in any of the other regions.

No significant laterality effect in the occipitolparietal region was observed in the SSVEP magnitude pointmaps of the BPM and CPM groups, but the SSVEP magnitude in the left occipitolparietal region of the BPF group was more pronounced than in the right occipitolparietal region. The EFT SSVEP phase pointmaps shown in the right hand column will be described in the difference maps section as the SSVEP phase difference maps.

**Difference Maps**

The difference maps of SSVEP magnitude and SSVEP phase shown in the left and centre column respectively of Figure 7.6 are the EFT task, of the BPM, BPF and CPM groups, subtracted from their respective Baseline task.

The topography of the BPM group SSVEP magnitude difference map indicates significant SSVEP magnitude reductions, with respect to the Baseline task, globally save the centrolparietal and occipital regions. There was a LH lateralization effect in SSVEP magnitude reduction in the temporolparietal region. The centrolparietal and occipital regions showed a significant SSVEP magnitude increase.

The topography of the BPF group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the frontal, right temporolparietal and occipital regions. Noticeable RH lateralization effects in SSVEP magnitude reduction was evident in the temporolparietal and frontal regions. The centrolparietal region showed a very, significant SSVEP magnitude increase.

The topography of the CPM group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the right occipito/parietal, frontal and temporal regions. A LH lateralization in
**Figure 7.6** The topographic maps are from the Best Performance Males (BPM), Best Performance Females (BPF) and Compatible Performance Males (CPM) groups. The Maps illustrate the difference in the SSVEP associated with the Visual Vigilance (Baseline) and EFT tasks. Column 1 indicates the magnitude differences. Column 2 indicates the phase differences, while Column 3 illustrates the distribution of the square root of Hotelling's $T^2$ (T) based on paired comparison between the two tasks. The Iso-T values illustrated correspond to single comparison p values of 1 %, 0.5 % and 0.1 %.
SSVEP magnitude reduction was evident in the temporal region. A weak RH lateralization in SSVEP magnitude reduction was evident in the occipitoparietal region. A significant SSVEP magnitude increase was evident in the centro/parietal region.

In examining the SSVEP phase difference maps the BPM demonstrated the largest phase lag in the right occipito/parietal region, as did the CPM. The BPF demonstrated the largest phase lag in the right temporo/parietal region. The BPF showed the most significant phase advance in the frontal region, with the CPM showing significant phase advance globally save the occipitoparietal region. The most significant phase advance in the BPM occurred in the temporo/parietal and right prefrontal regions.

**Hotelling’s T Probability Maps**

The Hotelling’s T probability maps illustrated in the right hand column of Figure 7.6 are the EFT task, of the BPM, BPF and CPM groups, compared with their respective Baseline task. The topography of the probability maps indicates that the most consistent effects were in the left temporal and frontal regions, particularly the prefrontal regions, for the BPM and CPM. In the BPF the most consistent effects were observed in the frontal region. Of the three groups the consistent effects were weakest in the BPF.

Overall, the observed effects were stronger in the BPM (T = 11.3, d.f. = 7, 1, p < .001) than the CPM (T = 9.9, d.f. = 7, 1, p < .001), with the effects in the BPF being considerably weaker (T = 5.0, d.f. = 7, 1, p < .005).

**Worst Performance Groups and the EFT**

**Pointmaps of Baseline Task**

The pointmaps in the left hand column in Figure 7.7, illustrating the SSVEP magnitude from the Visual Vigilance task, were from the Worst Performance Male (WPM) and Female (WPF) groups, as well as the Best Performance All (BPA) group.

The topography of the three pointmaps is similar in that the maximum SSVEP magnitude occurs in the occipitoparietal region in all three pointmaps. The occipitoparietal effect was more pronounced in the WPM and WPF than the
Figure 7.7  The topographic maps are from the Worst Performance Males (WPM), Worst Performance Females (WPF) and Best Performance All (BPA) groups. Column 1 illustrates the distribution of the SSVEP magnitude during the Visual Vigilance (Baseline) task. The magnitude is expressed in terms of the mean SSVEP magnitude at all 64 sites. Column 2 illustrates the equivalent distribution during the EFT with Column 3 illustrating the distribution of the SSVEP phase during the EFT referenced to the Visual Vigilance task phase.
BPA, with a very slight laterality effect found in all three groups, where the left occipital-parietal region showed a more pronounced SSVEP magnitude than the right occipital-parietal region.

**Pointmaps of Embedded Figures Task**

The pointmaps in the centre column in Figure 7.7, illustrating the SSVEP magnitude from the EFT, were from the WPM, WPF and BPA groups. The SSVEP magnitude in the occipital-parietal region of the WPM, WPF and BPA groups was much larger than in any of the other regions. No significant laterality effect was observed in the occipital-parietal region in the WPM and BPA groups, but a weak LH lateralization was evident in the BPF. The EFT SSVEP phase pointmaps shown in the right hand column will be described in the difference maps section as the SSVEP phase difference maps.

**Difference Maps**

The difference maps of SSVEP magnitude and SSVEP phase shown in the left and centre column respectively of Figure 7.8 are the EFT task, of the WPM, WPF and BPA groups, subtracted from their respective Baseline task.

The topography of the WPM group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, only in the left occipital-parietal, and a weak effect in the frontal region. There was a LH lateralization effect in SSVEP magnitude reduction in the occipital-parietal region. The temporol-parietal region, and particular the centrol-parietal region, showed a significant SSVEP magnitude increase.

The topography of the WPF group SSVEP magnitude difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the temporoparietal and occipital-parietal regions. A significant LH lateralization effect in SSVEP magnitude reduction was evident in the temporoparietal region. The centrol-parietal region showed a significant SSVEP magnitude increase.

The topography of the BPA group SSVEP magnitude, difference map indicates SSVEP magnitude reductions, with respect to the Baseline task, in the occipital-parietal, temporol-parietal and frontal regions. A weak RH lateralization in SSVEP magnitude reduction was observed in the frontal and temporol-parietal
Figure 7.8  The topographic maps are from the Worst Performance Males (WPM), Worst Performance Females (WPF) and Best Performance All (BPA) groups. The Maps illustrate the difference in the SSVEP associated with the Visual Vigilance (Baseline) and EFT tasks. Column 1 indicates the magnitude differences. Column 2 indicates the phase differences, while Column 3 illustrates the distribution of the square root of Hotelling’s $T^2$ ($T$) based on paired comparison between the two tasks. The Iso-$T$ values illustrated correspond to single comparison $p$ values of 1 %, 0.5 % and 0.1 %.
regions. A significant SSVEP magnitude increase was evident in the occipital and centro/parietal regions.

In examining the SSVEP phase difference maps the WPM demonstrated significant phase lag in the left temporo/parietal region and left frontal region. The WPF demonstrated the largest phase lag in the left temporal region, whilst the BPA demonstrated the largest phase lag in the occipito/parietal region and right temporal region. The WPM showed the most significant phase advance in the left prefrontal region and right temporolparietal region. The WPF showed the most significant phase advance in the frontal region, which was the most significant of the three groups. The most significant phase advance observed in the BPA group was in the left temporal region.

**Hotelling’s T Probability Maps**

The Hotelling’s T probability maps illustrated in the right hand column of Figure 7.8 are the EFT task, of the WPM, WPF and BPA groups, compared with their respective Baseline task. The topography of the probability maps indicates that the most consistent effects were in the frontal regions in the WPM and WPF. In the BPA group the most consistent effect was in the right temporal region.

Overall, the observed effects were stronger in the WPF (T = 7.3, d.f. = 7, 1, p < .001) than the WPM (T = 6.7, d.f. = 7, 1, p < .001) and BPA (T = 6.8, d.f. = 7, 1, p < .001), although the difference was not large.
INSTRUCTIONS FOR DOING MENTAL ROTATIONS TEST

. The Mental Rotations Test (MRT) is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original object and the chosen object will be that they are presented at different angles.

An illustration of this principle is shown on the screen (Diagram A), where the same single object is given in five different positions. Look at each of the objects with respect to the centre object and satisfy yourself that they are only presented at different angles from the centre object.

On this card (Diagram B) are two drawings of new objects. They cannot be made to match the five drawings on the screen. Please note that you may not turn over the objects. By this is meant that the top of the object cannot be flipped over so as to become the bottom, and vice versa. One should try and visualize the 2-Dimensional presentation of the object as being rotated in 3-Dimensions about a vertical type axis. Satisfy yourself that the objects on the card are different from the five objects on the screen.

A sample problem will now be shown on the screen (Diagram C), along with the correct matches. The correct matches being the objects marked with a cross in the box underneath the object. For each problem there will be a primary object in the centre of the screen, as illustrated on the screen. You are to determine which two of the four objects surrounding the primary object in the centre are the same as the primary object in the centre. There will Always be TWO correct matchings and TWO incorrect matchings. You will use a box with FOUR buttons on it. Each button corresponds to one of the four objects on the screen that surround the primary object in the centre. For example, the top left hand button, with letter (A) besides it, corresponds to the object on the top left of the screen. You are to press the TWO buttons, in any order you choose, which you believe correspond to the CORRECT matching objects, and NOT to press any button for the incorrect ones. The screen will change pictures automatically every 18 seconds, so you have 18 seconds in which to press the buttons. You need NOT press both buttons if you are UNSURE, as you will be penalised on your score for incorrect responses. It is best to press one button as soon as you find a correct match, and then to press the second button if you manage to locate
the second matching object within the 18 second time limit. It is unwise to try and guess the second matching object, because if you guess wrong, then your overall score will be zero, regardless of whether you answered the first one correctly. On the other hand, if you only press one button, and your answer is correct, then you score one point. If you press the same button twice it won't register your second response, and also, if you press the wrong button, then you CANNOT correct your answer, so be CAREFUL to press the RIGHT button. You will be SCORED on this test as follows:

- TWO Correct -- 2 Points.
- ONE Correct & ONE Incorrect -- 0 Points.
- ONE Correct & Only ONE Button Pressed -- 1 Point.
- ALL Else -- 0 Points.

TOTAL Possible SCORE is 40 Points.

Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea as to which choice is correct. When you do the test on the computer you will first do some sample problems, WITH NO SET TIME LIMIT, before doing the main test. In all, the MAIN test consists of 2 Separate Parts, with each part lasting for about 3 minutes.

Accuracy is more important than speed in this test. This test is not an easy one, but you are asked to remain relaxed throughout the task. If you don't respond within the set time limit of 18 seconds then don't worry about it, just go on to the next task. The main objective of this task is to record your brain activity while you are performing the act of mental rotation, and the mental rotation test was chosen as it is an efficient stimulus that will get you to use this visuospatial cognitive ability.

Your first task will be to do the three sample problems, which you can do at your own pace, as there is no time limit. The correct answers will be shown to you at the completion of each sample problem, but you will not be shown the correct answers in this manner when doing the main task. Do you have any questions?

GET SUBJECT TO DO SAMPLE PROBLEMS AFTER QUESTIONS.
Please note

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