The Psychophysiology of Flow States

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Abstract

This interdisciplinary neuroscience thesis investigated the cognitive and neurocognitive underpinnings of flow states and developed an alternate model as well as a possible intervention to facilitate entry into flow. Csikszentmihalyi (1975) first described the flow state, noting the conditions for entry include a balance of a person's skills with challenges or action opportunities as well as clear and well-defined goals with immediate feedback. This research is interested with the current environments of work and play, where one is constantly bombarded with messages, meetings and social media that can make it very difficult to stay focused and productive during a task. All facets of society are interested in facilitating a way for people to be able to function optimally for tasks in a seamlessly efficient manner, regardless of whether they are recreational or occupational.

Reports of transcendent, spiritual experiences similar to experiences of flow states have been written about in religious texts for centuries, yet much of its inner workings and route of initiation is still shrouded in mystery. Psychological research into flow states is still young with the literature fractured on different theoretical models and using conflicting language across different fields to find conflicting results. Nonetheless, much advancement has moved forward through the introduction of quantified flow state scales and more sophisticated modelling techniques to help understand the nuance of flow states. Therefore, as flow states have been shown to couple with complex cognitive tasks as well as a high level of intrinsic motivation, the cognitive component of the first flow study presented in this thesis employs an online questionnaire to investigate the different cognitive strategies employed to move into flow in different contexts.

Specifically, the extent to which mindfulness, focusing one's attention to experiences occurring in the present moment, mediates the relationship between personality factors (need for cognition and active coping strategies) with the experience of dispositional flow examined across recreational and occupational contexts.

Furthermore, neuroscience flow research has limited studies with conflicting models that presently only relay part of the story. The neurocognitive section of this thesis assessed the similarities and conflicts between the existing neuroscience literature to present a new model combining and complementing these existing models. Additionally, a second flow study of this thesis investigate the functional neural networks that facilitate entrance into flow states with transcranial direct current stimulation (tDCS) across differing levels of expertise in 1) a domain general experiment using electroencephalography (EEG) with a temporally occluded soccer goalie task and 2) for video gamers entering into flow states.

The cognitive research results revealed mindfulness significantly mediated the relationship in professional settings and overall for flow states, but not in recreational settings. For the neurocognitive component of the research the domain general task revealed spectral power changes in a range of frequencies in experts as they only demonstrated significant improvements in predicting ball direction for the overall and early occlusions after tDCS. However, for the flow tasks tDCS increased flow experience for all level of video game expertise.

The research contributes to academic cognitive and neurocognitive literature to provide new understanding about the role of cognitive strategies in different contexts as well as a new theoretical model in which to guide future neurocognitive studies for flow

states. Additionally, from an applied perspective this research could result in facilitating performance improvements to provide a better understanding of how to facilitate greater productivity in different recreational and occupational contexts.

Keywords: flow, tDCS, EEG, mindfulness, internal models, need for cognition, coping, decision making, expertise

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about. But of course, your celebrations of my achievements and commiserations of my setbacks are worth more than what money could ever buy… love.

Declaration

This thesis contains no material which has been accepted for the award to the candidate of any other degree or diploma, except where due reference is made in the text of this thesis. To the best of my knowledge, this thesis contains no material previously published or written by another person except where due reference is made in text. Where the work is based on joint research or publications, this thesis discloses the relative contributions of the respective authors. I warrant that I have obtained, where necessary, permission from the copyright owners to use any third party copyright material reproduced in the thesis (such as artwork, images, unpublished documents), or to use any of my own published work (such as journal articles) in which the copyright is held by another party (such as publisher, co-author).

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Academic Publications

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Review paper: Submitted

Gold, J. and Ciorciari, J. (2020) A review on the role of the neuroscience of flow states in the modern world. Behavioral Sciences, (Submitted July 2020)

Publication 2: Peer Reviewed Paper

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List of Abbreviations

Chapter1: Introduction

ESM experience sample method

FSS flow state scale

ECG electrocardiography

EMG electromyography

EEG electroencephalography

fMRI functional magnetic resonance imaging

DLPFC dorsolateral prefrontal cortex

TOP temporal, occipital and parietal cortices

THH transient hypofrontality hypothesis

fNIRS functional near-infrared spectroscopy

FP1 electrode prefrontal 1

FP2 electrode prefrontal 2

STF synchronization theory of flow

COVIS competition between verbal and implicit systems

LTP long term potentiation

tDCS transcranial direct current stimulation

MPFC medial prefrontal cortex

MEG magnetoencephalography

Fpz central prefrontal zone

Chapter 2: A neurocognitive model of flow states and the role of cerebellar internal models

ECG electrocardiography

EMG electromyography

EEG electroencephalography

fMRI functional magnetic resonance imaging

THH transient hypofrontality hypothesis

STF synchronization theory of flow

BG basal ganglia

fNIRS functional near-infrared spectroscopy

DMN default mode network

MPFC medial prefrontal cortex

tDCS transcranial direct current stimulation

TPJ temporoparietal junction

ACC anterior cingulate cortex

SMA supplementary motor area

IO inferior olive

pRN parvocellular red nucleus

P instructor

CT controller

CO controlled object

MM mental model

VC visual cortex

SS sensory system

IM inverse model

FM forward model

Chapter 4: Methodology

P3 Publication 3

P4 Publication 4

P5 Publication 5

MEG magnetoencephalography

tDCS transcranial direct current stimulation

EEG electroencephalography

FPS 1st person shooter videogame

ICA independent component analysis

Chapter 5: The moderating role of mindfulness in predicting flow traits during recreation and work.

NFC need for cognition

FFMQ five facet mindfulness questionnaire

DFS dispositional flow scale

CFI comparative fit index

RMSEA root mean square error of approximation

SRMR standardized root mean squared residual

MI modification indices

Chapter 6: Impacts of transcranial stimulation on sports occlusion task and its frequency power profile

tDCS transcranial direct current stimulation

AON action observer network

DLPFC dorsolateral prefrontal cortex

ERSP evoked response spectral power

ANOVA analysis of variance

Chapter 7: A transcranial stimulation intervention to support flow state induction.

tDCS transcranial direct current stimulation

DLPFC dorsolateral prefrontal cortex

FPS 1st person shooter videogame

BA Brodmann's area

MPFC medial prefrontal cortex

ANOVA analysis of variance

PPC posterior parietal cortices

ACC anterior cingulate cortex

EEG electroencephalography

fMRI functional magnetic resonance imaging

SUHREC Swinburne university human experimentation committee

Chapter 8: Discussion

EEG electroencephalography

tDCS transcranial direct current stimulation

THH transient hypofrontality hypothesis

tACS transcranial alternating current stimulation

tcDCS cerebellar transcranial direct current stimulation

AON action observer network

Chapter 1: Introduction

1.1 Publication 1: Rationale

This introductory chapter provides a literature review that explores the current flow state literature by addressing the environmental influences as well as the cognitive and neurocognitive elements that underlie the experience. In particular the research focusses on the transition of cognitive control from an explicit to an implicit process. This is further expanded upon to look at the current, yet related neurocognitive research of high performance associated and the implicit process of automaticity. Finally, the review focusses on transcranial direct current stimulation (tDCS) as a novel method to facilitates an induction of flow states. Implications are aimed at a general technique to improve on skill acquisition and overall performance. Submitted publication 1 is included in this chapter.

1.2 Publication 1: A review on the role of the neuroscience of flow states in the modern world

1.2.1 Introduction to flow

The scientific community has as of late begun to explore the field of expertise and its components. One element however that has begun to gain a growing amount of attention is the peak performance found in flow states, whether it be in sport, business or other professional endeavor. Flow is described as a state of optimal performance denoted by smooth and accurate performance with an acute absorption in the task to the point of time dissociation and dissociative tendencies (Csikszentmihalyi & Csikszentmihalyi, 1988; Nakamura & Csikszentmihalyi, 2002; Rheinberg, Vollmeyer, & Engeser, 2003). In the modern workplace there are so many distractions, from messages to meetings, that result in a reduction of productivity. Yet a 10-year longitudinal study Cranston and Keller (2013) showed people in flow states were 500% more productive. Whilst much research has been performed on the personality components of flow there is still much to explore when it comes to the neurocognitive underpinnings of flow to better understand the workings and catalysts for this elusive state.

Transcendent, spiritual experiences similar to flow states have long shared reports with countless of religious references dating back centuries by spiritual authors. Flow then found its entrance into the mainstream with Maslow (1964) ‘peak experiences’ and has since been appropriated into popular culture with many names including “in the zone” and “in the moment”. Although a long history exists of this high functioning state, much of its inner workings and route of initiation is shrouded in mystery. Csikszentmihalyi (1975) first described the flow state, noting the conditions for entry include a balance of a person's skills with challenges or action opportunities as well as clear and well-defined goals with immediate feedback.

According to Csikszentmihalyi's (1997) flow theory, the flow experience relates to the skill set perceived to be possessed by the individual relative to the perceived challenges of the activity. Challenges can be considered as "opportunities for action" thus flow is produced by any situation that requires skill (Csikszentmihalyi & Csikszentmihalyi, 1988). The phenomenology of flow further suggests that the enjoyment of a task is due to a discovery found within the interaction of the task. For instance, at first the task might appear boring or anxiety provoking but if the action opportunities become clearer or the skill level improves the task becomes more engaging and finally enjoyable. The discovery of more complex behaviors results in an emergent motivation that transforms a previously unengaging task into that which is intrinsically motivating (Csikszentmihalyi, Abuhamdeh, & Nakamura, 2005). Therefore, complexity of the skill must increase to meet the increasing complexity of the task's challenge in order for the person to remain in flow. Csikszentmihalyi (1997) developed the flow state model to help illustrate this state change as seen in Figure 1.1. For instance, when challenges and skills are low, a person will likely experience apathy, considered an experience of the lowest quality and the lowest intensity on the flow state model. Whereas, when skills are higher than those needed for challenges, the person is more inclined to experience boredom/ relaxation, considered an experience of higher quality than apathy. As the level of challenge increases, the experience moves toward control. In contrast to this, as challenges are higher than the skills required by the person, the experience of worry/ anxiety is more likely. Then as the skill level increases, the experience moves toward arousal. Therefore, based on this model, flow states are believed to be accessed when skills and challenges are both high and in equilibrium, resulting in the highest state experience (Csikszentmihalyi, 1990).

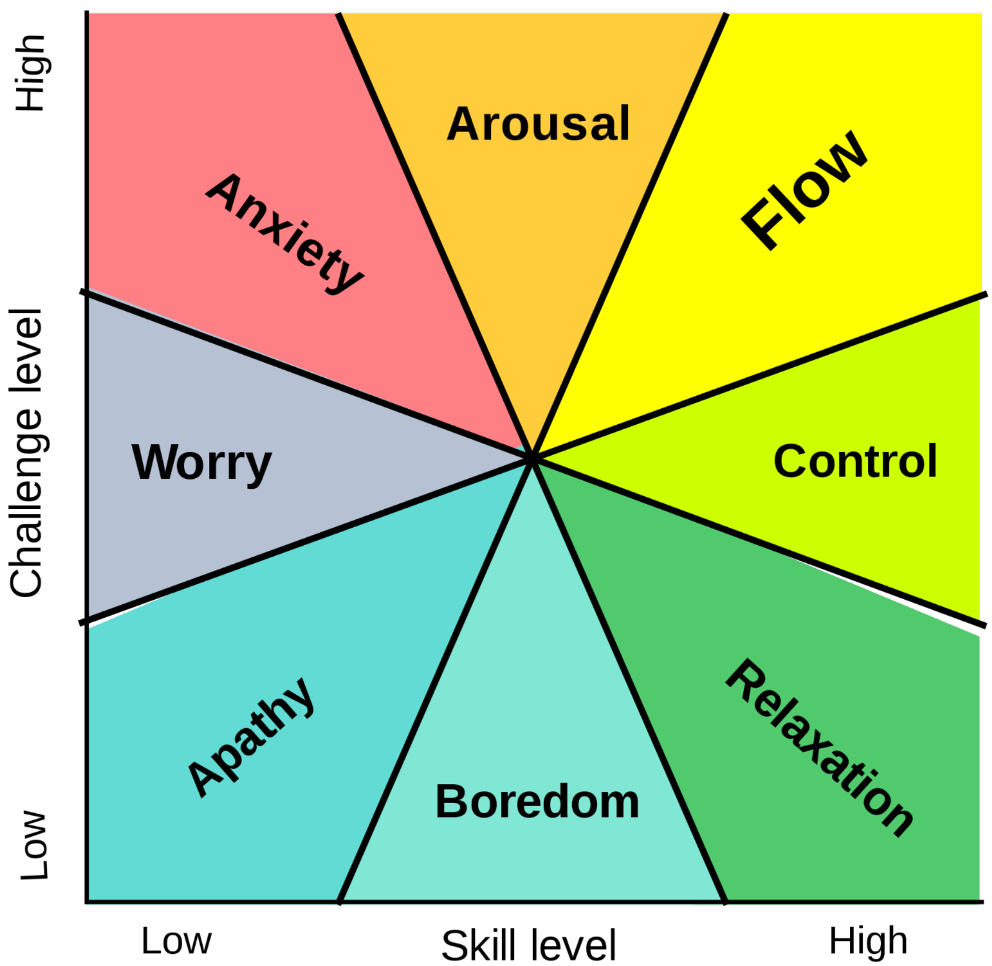

Figure 1.1: Csikszentmihalyi's (1997) flow model describes psychological states in terms of challenge level and skill level.

Nonetheless, flow rarely occurs in everyday life due to a rare balance of skills challenges, nonetheless even this delicate balance across these two parameters does not guarantee flow. Therefore, flow requires activities to have a further set of particular criteria (Csikszentmihalyi, 1990). Firstly, the flow activity typically requires a learning of skills, as well as having clear goals with quick and unambiguous feedback. This affords a sense of control over reality by understanding what needs to be done and how they are performing. This activity design also works best when concentration and involvement is facilitated by separating a person from their everyday existence by focusing on the particular reality of the activity, such as particular uniforms and special rules of the activity that are not necessarily relevant to everyday living (Csikszentmihalyi, 1990).

People in flow mention that they become so absorbed in the activity that they don't have any attention to spare to become distracted by anything else. People have also mentioned a collection of other psychological phenomena associated with states. These include: a) a feeling of control over the task; b) an experience of time distortion, in which a person loses awareness of how time is passing c) the removal of self-consciousness in which a person loses the awareness of themselves as well as thoughts of everyday problems; d) a feeling of transcendence where the person feels a sense of unity with the activity. See Table 1.1 for a list of full 9 components.

1. Clear goals (expectations and rules are discernible, and goals are attainable and align appropriately with one's skill set and abilities).
2. High level of concentration, a high degree of concentration on a limited field of attention (a person engaged in the activity will have the opportunity to focus and to delve deeply into it).
3. A loss of the feeling of self-consciousness, the merging of action and awareness.
4. Distorted sense of time, one's subjective experience of time is altered.
5. Clear and immediate feedback (successes and failures in the course of the activity are apparent, so that behavior can be adjusted as needed).
6. Balance between skill level and challenge (the activity is neither too easy nor too difficult).
7. A sense of personal control over the situation or activity.
8. The activity is intrinsically rewarding, so there is an effortlessness of action.
9. People become absorbed in their activity, and focus of awareness is narrowed down

Table 1.1: Nine components associated with the flow state experience from Csikszentmihalyi (1990)

Therefore, when a person has a perceived adequacy of skills matched with above average challenges, as part of a goal-directed, rule bound framework providing accurate feedback, the person can find complete absorption that removes the possibility of any distractions from thoughts not relevant to the present task. In this focused space a person has an opportunity to find such a level of immersion in the activity that they will feel an inspired sense of control, a complete removal of self-consciousness, a distortion of time and a feeling of transcendence.

Furthermore, it has also been found that flow states can be reached by any person performing any sort of task as long as they can attain an adequate level of skill. These levels of skill require an expertise that can afford the smooth performance state associated with flow and consequently it is believed that greater expertise results in higher flow experiences (Rheinberg, 2008). Many people were studied in many different situations and all were able to achieve the optimal experience from the activity. Flow states have become common place in all areas of society that people use many ways of describing the state such as “wired in”, “in the groove”, “in the moment” and “the zone” to name a few. This experience has typically been described throughout the ages as forms of religious fervor but now has moved into the current day through many other forms of engaging activities. Flow has been recorded in everything from business transactions, sports, video gaming, music, art and yoga. These flow states all share in a series of similar characteristics that were attributed to flow by Csikszentmihalyi. It is the subjective, rather than objective, challenges and skills that impact on the quality of a person’s experience. (Csikszentmihalyi, et al, 2005). Numerous studies have further highlighted the similar subjective experience of flow states in various activities, such as sport (Jackson, 1996), gambling (Trivedi & Teichert, 2017), skateboarding (Seifert & Hedderson, 2010), education (Rogatko, 2009) to name a few. No matter what the activity, the elicitation of this flow state is considered by many to be the “Holy Grail” of performance (Becker, 2017).

1.2.2 Environmental influences on flow

Even when one has satisfied the conditions stipulated as necessary to reach the flow state, this however still does not conclusively answer how certain people are able to reach this state nor why and whether all people are able to attain such a state (Fong, Zaleski, & Leach, 2015). One element noted by Csikszentmihalyi that influences entrance into flow states is the level demanded by the critical implications of the activity (Csikszentmihalyi, 1990). This has been shown to translate onto a normative continuum as the flow experience is based on the task’s personal importance. For example, surgery and mountain climbing are highly critical tasks, which are more often reported to result in intense, ecstatic flow experiences whereas absorbing yet less critical tasks such as reading, and video games have less intense flow experiences.

Additionally, flow states have been shown to be moderated by the level of perceived importance a person places on a task. Engeser and Rheinberg (2008) showed how the level of importance impacts the skill/ challenge requirements. During activities considered important such as exams, high flow levels were associated with low challenge while activities considered of lesser importance such as for Pac-Man, flow was high when there was a skills/ challenge balance but lowest if the challenge was overly high or low. Additionally, this study showed the importance of achievement motives, based on the risk taking models of Atkinson (1957), who showed how the explicit motivation for fear of failure and the implicit motivation for hope of success influenced the preference towards a balance of challenge and skill. In particular, people with the hope of success are more likely to experience flow during balanced skills/ challenge task compared to people with a high fear of failure who experience lower flow when balanced.

In considering these additional implications of criticality, importance and achievement motives, these lead to the introduction of environmental aspects such as the role of the task. For instance, how do these elements apply to work compared to recreational tasks? A study by Csikszentmihalyi and LeFevre (1989) showed surprisingly flow was 300% more likely to occur at work compared to recreation. However, even within work it depends on the role. For instance, managers reported the highest levels of flow in work while general workers reported the highest level in recreational flow. Furthermore, a recent study by Viljoen (2018) of part time and occupational musicians on the experience of flow looked at these elements to show the differences in their approach to the task. Occupational musicians showed a significant connection between mindfulness and frequency of playing which is associated to accessing flow. While part time musicians considered the time required of occupational musicians were routine and likely inhibited flow. To clarify, mindfulness has described as a connecting bridge between our mind and the present moment, allowing the person to stay aware of what is happening in that very moment (Kabat-Zinn, 2009). Therefore, mindfulness appears to share similar attributes that may support flow state facilitation. Additionally, the struggle of financial security for occupational musicians placed stress on many musicians which also was distracting from achieving flow states. These considerations are relevant to better understanding how flow states are influenced by different contexts and could be explored further in order to expand on the understandings of the cognitive roles that impact access and movement into flow states. Therefore, an aim in this thesis will consider the difference of recreational and occupational roles and the related levels of task frequency regarding perceived expertise when measuring flow states.

When delving further into what flow is and how far reaching and common flow states are in modern society, it is also important to understand why flow is so relevant to modern day society. In the modern workplace, there are so many opportunities to be distracted from work with messages, meetings and social media, it is difficult to not become distracted or overwhelmed. When in a flow state, the individual is considered to perform at their full capacity (De Charms, 1968; Deci & Ryan, 1985). Flow has commonly been associated with intense concentration (Csikszentmihalyi, 1990), a higher behavioral efficiency and creativity (Canter, Rivers, & Storrs, 1985), as well as a heightened sense of playfulness (Webster & Martocchio, 1992). Furthermore, the intrinsic rewards associated with the autotelic experience of flow is considered to also increase learning efficiencies (Canter et al., 1985) and therefore more likely to result in seeking out these experiences more frequently as well as better recall of these experiences (Csikszentmihalyi 1990). This helps drives the person to ever-higher levels of complexity in the challenge of the activity, ultimately improving their skill level. Such increases have also been shown to impact positively on the associated group with many successful scientists, sports stars and artists mentioning flow as relevant to their work and improving their performance whether it be in sports, arts or workplace productivity (Csikszentmihalyi, 1991). Flow is also characterized by an elevated sense of self-control (Ghani & Deshpande, 1994) and higher positive subjective experiences (Csikszentmihalyi, 1997).

1.2.3 Flow Measurement

The primary method of studying flow has been through questionnaires as well as interviews for more qualitative explorations. For example, Larson and Csikszentmihalyi (1983) developed the experience sample method (ESM) which would ask participants to mark in real time at certain times throughout their day of their flow experience. The problem with this and other methods is, as was already stated, flow states require acute concentration to the point where little to no attentional resources is misallocated. Also, the individual experiences an absence of self-consciousness where self-reflective thinking and an anxiety of social evaluation are not present. Therefore, the introspection necessary for these measuring techniques has the danger of inhibiting the flow experience as it requires resources to be allocated to a different cognitive set as these are retrospective by nature (Swann, 2016).

Since ESM, the Flow State Scale (FSS) was introduced, which operationalizes flow by transforming it’s nine elements that equally spread over the composite flow scores (Jackson & Eklund, 2004). The FSS considers flow as a ‘degree’ of flow on a continuum instead of a discrete ‘peak’ experience, which can be used to portray the experiential quality as a level of intensity of flow within the activity (Csikszentmihalyi & Csikszentmihalyi, 1988). The intensity of a flow state is considered to elevate as more of its nine elements increase in score. The FSS is typically given at the completion of each trial so as not to force the participant out of the state during the action. Nonetheless, people will also experience a range of affective states across trial periods

(Peifer, Schulz, Schächinger, Baumann, & Antoni, 2014). Self-reported flow state scales at the end of a task measure the experience across the whole task rather than for a particular time period. This may further be influenced by the recency effect in memory which may color the memory of the entire trial by the most recent experience toward the end of the trial (Brewer, Van Raalte, Linder, & Van Raalte, 1991). Such pitfalls of studying the dynamics underpinning flow states limit how far researchers explore this elusive state to optimal performance and our understanding of consciousness. Researchers have since begun to address this limitation through the use of psychophysiological methodologies, which focus on the expression of psychological phenomena in bodily processes, to explore the dynamic nature of flow experience throughout the entire task.

Psychophysiological measures have been employed to explore the more complex physiological aspects of human consciousness such as hypnosis, meditation and sleep. These measures include electrocardiography (ECG), electromyography (EMG) and skin conductance and have begun to be utilized in the study of flow states. More recently electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are shedding new light on the neurocognitive elements of flow states. However, these studies have not accumulated enough evidence to define a common acceptance of the neurocognitive functioning and thus researchers continue to address flow states from different methodological backgrounds and these different motivations result in differing perspectives. Select studies have now begun to measure flow states and demonstrate the psychological effects of flow with physiological results utilizing various physiological variations to justify experimental design decisions, yet this results in conflicting results from multiple research queries. Therefore, during this exploratory phase, precise research questions are still ill-defined due to the disparate results.

1.2.4 Flow neurocognitive mechanisms

As flow research has continued to delve deeper into its neural functioning, theorists have naturally moved to explain the neurocognitive mechanisms underpinning the state. Dietrich (2000) proposed a flexibility/ efficiency trade off, which addresses the balance between implicit and explicit processing systems used to acquire, memorize and represent knowledge (Sun, 2001). Theories of implicit/ explicit processing has been guided by the modern understanding on neuroscience which assumes a more hierarchical development of cognitive functions where an increase of integrated neural structures continues to increase the level of complex processing. Therefore, Dietrich (2004) introduced the first neurocognitive model for flow states as the transient hypofrontality hypothesis (THH) which considered flow a state of transient downregulation of the highest cognitive hierarchical component, the prefrontal cortices, defining flow processes in the form of transition from explicit to implicit information-processing systems.

Ashby & Maddox (1998) found a consensus about the nature of the explicit system, different to the implicit system, as a rule based system linked to language function and conscious awareness across many tasks, e.g., the serial reaction time task (Jiménez, Vaquero, & Lupiánez, 2006), the dynamic control task (Berry & Broadbent, 1988) and many others. However, there is still contradictory evidence found in the explicit reasoning ability of Köhler's (1925) apes despite their presence of a form of language. Nonetheless, whilst verbalizability appears to be the general standard, a better theoretical principle is still needed for conscious awareness. Conscious awareness has been described along similar lines as the implicit and explicit system with both on and offline systems that work to establish consciousness. Systems offline to consciousness are reflexive, rigid and fast responding, such as a frog snapping at a fly. However, as it is organizationally inefficient to house the ever-increasing number of complex reflexes, a more effective system proposed would be to include a temporary buffer that enables the organism to examine multiple representation of the plan of action before making a decision (Crick & Koch,1998).

Conscious online elements appear to share a close relationship with working memory and executive control. Executive control directs our attention and the working memory. It also links the past, present and future by providing a moment-to-moment connectivity. Findings on the association between the prefrontal cortex with this prevailing model was developed by Crick and Koch (1998) which states that conscious awareness can only exist if the brain activity projects to the prefrontal cortex. Crick and Koch's theory however is not a complete theory of conscious awareness and therefore we are relegated to using the operational definition that explicit processes are able to be explained verbally.

Studies have started identifying the prefrontal regions involvement with the explicit system based on evidence from the dorsolateral prefrontal cortex (DLPFC) acting both as a working memory buffer for the content of consciousness, as well as selecting content through the executive attentional network (Ashby & Casale, 2002; Dehaene & Naccache, 2001) The medial temporal lobe has also been identified as relevant underlying circuitry (Poldrack & Packard, 2003). An argument has been presented that the explicit system is a younger evolutionary occurrence that is present for animals that have more complex prefrontal cortices (Dietrich, 2003). Support is found for this in the late phylogeny and ontogeny development of the prefrontal cortex (Fuster, 2002). Furthermore, the structure of information processing is known to be hierarchical and due to the sophistication of the explicit knowledge representation, such higher order structures are believed to be localized in the prefrontal areas (Dietrich, 2003).

Two distinct parallel processing tracts have been identified that traverse the brain and process the incoming information differently. The emotional tract processes more typically in a non-algorithmic skill-based manner that attaches values to help evaluate the biological significance of the information. The second tract performs detailed featured analysis in a computational mode free from any interpretations of salient information. Whilst both pathways begin to converge at the thalamus, the cognitive pathway feeds through the hippocampal formation and temporal, occipital and parietal cortices (TOP), helping provide a degree of selective attention required to process incoming information (Taylor, 2001).

As connections continue to take place along the hierarchical pathways, full convergence appears to occur at the DLPFC (Fuster, 2000). The DLPFC is primarily involved in executive functioning, enabling higher functionality including self-reflective consciousness, abstract thinking, and theory of mind (Yuan & Raz, 2014). It further plans, formulating appropriate strategies and subsequently directs the motor cortices to initiate the process. It is at these prefrontal functioning in which the control over the cortices are the most sophisticated. The DLPFC is also responsible for temporal integration (Fuster, 1995), directed and sustained attention (Sarter, Givens, & Bruno, 2001), and working memory (Fuster, 2000a), which facilitate an intricate cognitive framework that actively attends to information, thus affording a buffer for retaining information in the moment, whilst organizing it in space-time (Dehaene & Naccache, 2001).

This cognitive tract is broken up into two attentional tracts of its own: Top down and bottom-up processing. As explained by Corbetta and Shulman (2002), voluntary shifts of attention are thought to be mediated by the dorsal frontoparietal system resulting in goal-directed, “top-down” control utilizing information based on current circumstances such as finding your way home. On the other hand, the ventral frontoparietal system mediates the automatic “bottom-up” claiming of attention guided by salience inherent in the stimuli, such as your unique and alarming ringtone. The DLPFC has been shown to exhibit a top-down functionality which inhibits maladaptive and inappropriate cognitive and emotional behavior (Lhermitte, Pillon, & Serdaru, 1986). The frontal lobes appear to be based on more universal principles which inhibit people from compulsively acting on immediate cues (Crews & Boettiger, 2009). Therefore, the frontal lobes help free us from being tethered to direct environmental triggers. It is the inhibitory abilities of the top-down processes that allow a person to remain task focused and not be guided by more salient bottom up processes (Gaspelin & Luck, 2018).

1.2.5 Neurocognitive models of flow

The two predominant neurocognitive theories of flow states have helped guide flow research to better understand its function in order to be able to further support access and entry into flow. The first, transient hypofrontality hypothesis (THH) by Dietrich (2004) proposes that during flow states, these explicit executive functions of the frontal cortices are inhibited. This reduction of frontal activity is expected to reduce interference from explicit processing such as self-referential thought and thereby freeing up more resources to be dedicated to the faster implicit processing system such as actioning of automatized processes. Recently studies have begun using psychophysiological measures to test the THH of flow experiences with a variety of testing for EEG with shooting (Bertollo, 2014), arithmetic (Katahira et al., 2018), video games (Castellar, Antons, Marinazzo, & Van Looy, 2019) and memory tasks (Fairclough, 2008), as well as fMRI for arithmetic tasks (Ulrich, Keller, & Grön, 2016; Ulrich, Keller, Hoenig, Waller, & Grön, 2014). For instance, Hirao (2014) conducted a near-infrared spectroscopy (fNIRS) on occupational therapy students who completed a verbal fluency test. Whilst there were only 2 channels in the study (FP1/2), the results supported the THH in which a negative correlation was associated between higher flow states resulting in a suppression of prefrontal activity.

However, the synchronization theory of flow (STF) proposed by Weber, Tamborini, Westcott-Baker, and Kantor (2009) disputes the THH due to many flow-like activities such as hypnosis and meditation showing strong frontal activity in neuroimaging studies occurring when in these altered states of consciousness as well as in flow studies (Harmat et al., 2015). Therefore, STF instead focusses on the neuronal efficient, feature binding processes of synchronizing neurons and networks to more effectively communicate and create “holistic, higher-order experiences” that resemble flow states.

STF’s foundation is based on Posner, Inhoff, Friedrich, and Cohen (1987) tripartite theory of attention that focuses on the neurocognitive structures of attention including the frontal and parietal cortices relating to “alerting” (the process of becoming aware of a stimulus), the top-down componentry of the dorsal attention network including the superior and inferior parietal lobes, the frontal eye fields, and the superior colliculus for “orienting” (allocating attentional resources to a stimulus), and the prefrontal “executive” regions for goal-directed processing. A few studies to date have provided support for STF (Huskey, Craighead, Miller, & Weber, 2018; Huskey, Wilcox, & Weber, 2018; Wolf et al., 2015), with one of the first fMRI studies by Klasen, Weber, Kircher, Mathiak, and Mathiak (2012), who broke down a video game into five operationalized elements of flow that can be observed as characteristics of the activity to find activation in relevant attention and reward structures that support the STF.

Whist there are fundamental differences in both THH and STF, they do share a similar belief in the role of the emotional tract in managing automatization of implicit processes as well as intrinsic reward. Implicit categorization has found less agreement with these theories than what has been found for the explicit system. While the role of explicit knowledge in consciousness is thought to create a more behaviorally flexible global workspace to test hypotheses (Baars, 1989), the role of implicit knowledge is considered instead to be more task-specific but less flexible due to the difficulty to access less conscious information (Karmiloff-Smith, 1992).

One thing agreed on is that the implicit system is not accessible to conscious awareness (Reber, 1989). However, unlike memory theorists (e.g., Schacter, 1998) who hold that ‘implicit’ implies no conscious awareness of the details of the information, or even that the information was stored. A weaker criterion is used for category learning, which only requires that the nature of learning has no conscious access (Ashby & Maddox, 1998). However, there may be an awareness of some learning occurring because trial-by-trial feedback is typically present. For instance, when a participant receives feedback that their action was correct, they will understand and be conscious of a learning having taken place. Implicit categorization theory is relevant to flow experiences as the literature has stated such states require clear and timely feedback. When feedback has been removed people are then restricted to verbalized rules (Ashby, Alfonso-Reese, Turken, & Waldron, 1998).

There has been a lot of research also supporting the implicit system as experience or skill based and conveyed through performance rather than verbally (Ashby & Casale, 2003). Implicit categorization learning was shown in a study by Spiering and Ashby (2008) to provide optimal training results when the challenge level of the task begins with difficult examples and then move to easier examples after it is understood that no simple verbal rule is sufficient. Rather than getting locked into a verbalized single rule, implicit learning allows decision making to take a more integrative approach from different perceptual dimensions. This information integration approach is maximized only at the pre-decisional stage as two or more stimulus components are integrated (Ashby & Gott, 1988).

While it has typically been assumed that an exemplar-similarity-based system should dominate information-integration tasks (Allen & Brooks, 1991; Regehr & Brooks, 1993), COVIS instead assumes a procedural-learning system. COVIS, an acronym for “competition between verbal and implicit systems”, which describes the process of the verbal system dominating initially due to the strength of its connections but with task repetition the implicit system supersedes the explicit verbal system bias. Yet both systems remain active retaining a significant proportion of categorization judgments after learning is complete (Ashby, et al., 1998).

Although the neural substrates are less clear for the implicit system, the basal ganglia have most often been critically associated with implicit system (Poldrack & Packard, 2003). The basal ganglia are well connected collections of gray matter structures positioned at both the interior section of the limbic cortices and the upper region of the brainstem. This key region of the basal ganglia receives all extrastriate visual cortex projections, with about 10,000 visual glutaminergic connections to each caudate cell in the striatum (Wilson, 1995). Projections are then sent to various cortical premotor and prefrontal regions via two synaptic pathway convergences. The first synaptic connection is via the globus palladus and substantia nigra pars reticula which has dopaminergic connections while the second synapse of the ventral anterior nucleus of the thalamus projects off to premotor areas, specifically Brodmann’s Area 8 (Shook, Schlag-Rey, & Schlag, 1991).

COVIS places an emphasis on this synaptic convergence as an important site for procedural learning (Ashby et al. 2007). In particular, it appears there are three factors which contribute to cortical-striatal strengthening via long term potentiation (LTP): strong presynaptic; and postsynaptic activation; as well as dopamine release (Arbuthnott, Ingham, & Wickens, 2000; Wickens, 1993). While presynaptic and postsynaptic activations are considered to play an important role for LTP via stimulus driven high threshold sensory cortical cells (Malenka & Nicoli, 1999), dopamine is considered more as a reward-mediated training signal (Wickens, 1993). These synapses however weaken through long term depression if either postsynaptic activation or dopamine release is not present (Arbuthnott et al., 2000). This could occur for example if an incorrect response is given resulting in an absence of dopamine release or if only a weak response is recorder by the visual cortical cell. Maddox, Ashby, and Bohil (2003) showed support for an interesting prediction by this three-factor model that if feedback was delayed by more than 2.5 s then information integration learning would be severely inhibited. This appears to lend support to the notion that flow states may require timely and accurate feedback whereas explicit learning in rule-based tasks of equivalent difficulty could sustain delays.

Implicit systems are believed to process parallel tasks due to the limitations of bandwidth that exist in the working memory of the explicit systems (Halford, Wilson, & Phillips, 1998). Cowan (2001) presented evidence of the working memory capacity with a 4 ± 1 limit, after rehearsal and chunking were catered for. Therefore, the explicit system appears to be capacity limited, where information demands are too great parallel tasks are collapsed into fewer chunks deeming some information inaccessible (Halford, Wilson, & Phillips, 1998). Implicit systems on the other hand seem to not share the same limitations. When learning a new task such as driving a car, this is a multidimensional task with many elements working in parallel. While the cortex is considered to be utilized for managing the input of novel information due to the requirement of goal directed attention and flexibility, working memory typically would be overwhelmed as instructions typically involve more than four independent bits of information. Therefore, instructions could be broken down into smaller components that could then be combined into larger chunks once the skill is sufficiently acquired. The explicit instructions would form a mental representation of the task that requires the premotor, primary motor and parietal cortices, and the cerebellum, to implement it (Jenkins, Brooks, Nixon, Frackowiak, & Passingham, 1994). Because of the limited ability to combine items into chunks, learning slows down due to capacity restrictions. The basal ganglia are believed to be a passive observer during this time building its own representation of the action (Gazzaniga, Ivry, & Mangun, 1998). After sufficient practice, neural control is gradually shifted to the basal ganglia (Mishkin, Malamut, & Bachevalier, 1984) and also the supplementary motor cortex, motor cortex, thalamus, and hippocampus (Jenkins et al., 1994). Ultimately, this internalizes the pattern of this activity into “muscle memory” and thereby affords the basal ganglia primary control without much reliance placed on the prefrontal explicit regions (Ashby, Turner, & Horvitz, 2010). This internalization frees up computational space of the executive function for other activities such as observing the surrounding environment, due to a lessening of demand from working memory. This may be useful for flow as it frees the person from needing to focus on the skill of the task and gives more buffering room for anticipating the potential challenges of the task.

Furthermore, a basic level of skill acquisition is needed to have a flow experience, as the implicit system requires a series of learnt specialized and independent response patterns to output (Csikszentmihalyi & Csikszentmihalyi, 1988). These automated stimulus response procedures are believed to require many hours of highly dedicated practice. Learning of automated responses takes time because of the limited ability of the explicit working memory to transfer specialized and reflexive response patterns to the implicit system due to capacity restrictions (Dietrich, 2004; Mishkin, Malamut, & Bachevalier, 1984). Automaticity, in which thoughts and behaviours occur without the need for conscious guidance, can be both conscious and unconscious (Shiffrin & Schneider, 1977). Unconscious automaticity is defined as automatic processes that do not require any willful initiation and operate independent of conscious control (Happe, 2001). This is exemplified with a priming that biases further processing of an event without the person necessarily even consciously aware of the connection. Such as seeing a beer advertisement along with a hot day and suddenly realizing you are thirsty and want a beer.

Conscious automaticity is defined as automatic thoughts and behaviours that provide efficient implementation of an action by providing faster processing through the removal of conscious monitoring as well as the use of minimal attention capacity (Happe, 2001). The modern standard for determining automaticity is if the behaviour can be produced in parallel and without attention (Schneider & Shiffrin, 1977). Skill acquisition is generally conscious labored and slow and slower but becomes automatic with consistent and frequent practice. These mentally disparate processes are then repackaged into a fluid arrangement of actions that can be set off by a single thought (Attri, 2019). Furthermore, automaticity enables assumptions to be made based on experience which creates greater outcome predictability. The more a person monitors their intentions throughout their actions, the more their experience will be consciously willed and nonautomatic.

A key component of the basal ganglia, the dorsal striatum, has been associated with the role of automatized implicit learning, in particular it's volume increased after a skill acquisition period of a video game task (Erickson et al., 2010). It is also assumed that the striatum is an early evolution for human development due to the central location and its input role in the basal ganglia. The caudate nucleus of the striatum has also been shown as the primary input structure of the procedural learning system using the COVIS model (Ashby, Ennis, & Spiering, 2007). It is long known that to effectively multitask two things simultaneously requires one task to be implicit (Broadbent, 1958). Thereby, implicit systems are ultimately more efficient than their explicit counterpart. People that have entered into flow states often refer to an automatic processing in which they report task focused behaviour without conscious thinking which suggests a form of frontal inhibition required for successful entry into the state.

Furthermore, a key site of pleasurable experience of rewards is associated with the dopamine rich striatum, due to dopamine's role in rewarding behavior by predicting rewarding outcomes that would result in reward-seeking experiences (Frackowiak et al., 2003), which lends support to the autotelic nature of flow states. Because of the autotelic nature and high criticality of flow, we are moved to consider the role of novelty as relevant to the induction of flow states. In the novelty hypothesis, during a period of high criticality, when a person is exposed to a new situation that results in a challenge that is equal to the skill level, the person may be pushed up into a level in which their skill is just below the level of challenge being presented. This additional stimulation may be enough to absorb the final amount of explicit buffering systems in order to fully immerse the performer in the task.

Therefore, whilst the two principle flow theories of THH and STF differ in their overall flow functionality explanations, they do share an agreement in the role of the dopamine rich striatum, interconnected with additional functions of the basal ganglia, that allow the procedural memory to override the bottleneck of the explicit prefrontal systems after proper encoding of skill acquisition, in order to be able to facilitate automaticity and other flow phenomenon such as positive affect by engaging the superior parallel processing capacity of the implicit systems.

1.2.6 Exploration of flow functions

As flow states are considered a complex combination of multiple cognitive features it has been difficult to delineate specific neurocognitive markers. Studies for the most part still rely on a mix between psychophysiological measures and probing post-task self-report questionnaires. The conflict still remains that when the participant is required to think about the experience, they are forced to self-reflect which will move them out of the flow state. Based on this lack of evidence for flow states, this thesis aims to further support key elements that may be relevant to the neurocognitive functionality of flow states and begin to breakdown some of the key neurological elements to test that have been defined as key elements of flow states. Particular elements of flow to be defined are that it occurs within an activity which is balanced with an individual's abilities, whilst completely focused on the activity and thus self-referential thoughts are inhibited. However, we can look at previous studies looking at similar cognitive functions such as expert performance, creativity, focused attention and mental workload to help delineate neurocognitive landmarks that will help us identify the elements of flow activity.

The EEG is a well validated measure for investigating psychological states associated with skilled motor performance (Hatfield, Landers, & Ray, 1984; Lawton, Hung, Saarela, & Hatfield, 1998). In particular, results have highlighted the left frontal and temporal regions as playing key roles in expert performance with increased alpha power in EEG occurring for expert marksmen compared with novice shooters (Hatfield et al., 1984; Haufler, Spalding, Santa Maria, & Hatfield, 2000). EEG has also been used across a range of activities including weight lifting (Gannon, Landers, Kubitz, Salazar, & Petruizello, 1992), golf (Crews & Landers, 1993) and archery (Landers, Han, Salazar, & Petruzzello, 1994) all revealing a reduction in left hemispheric activity.

Furthermore, in a recent study, a comparison of neuro-anatomical characteristics also showed that expert divers have significantly increased cortical thickness in the left superior temporal sulcus compared to the non-athlete group (Wei, Zhang, Jiang, & Luo, 2011). The superior temporal gyrus houses several important cortical structures, including Wernicke's area understood as involved in the comprehension of language. To follow on, this pattern of increased alpha activity in the left temporal region has been most commonly interpreted as representing a reduction in cortical activations, reducing verbalizations associated with the left brain and enabling more resources to be allocated to the visual-spatial processes of the right brain (Vernon, 2005). This has been further supported by lower coherence estimates of left temporal regions with motor regions by expert marksmen (Deeny, Hillman, Janelle, & Hatfield, 2003). This pattern suggests less cortico-cortical communication and a suppression of analytic processing influence thus simplifying a complex process and alleviating the need for a division of cognitive resources.

Additionally, a key antecedent of flow utilizes the challenge/ skills-balance which indicates high mental workload from deep involvement in the activity (Csikszentmihalyi, 1990). This has been shown in psychophysiological studies on flow, in which decreased heart rate variability was shown during challenge/ skills-balance in a knowledge task (Keller, Bless, Blomann, & Kleinböhl, 2011). EEG has also been used to evaluate mental workload in which a reduction of alpha activity and an increase of theta is present due to the tasks increased difficulty levels (Rugg & Dickens, 1982). Alpha frequencies are categorized into three frequency bands (8-13 Hz, 8-10 Hz, and 11-13 Hz). Alpha activity in general (8-13 Hz) represents lower levels of consciousness and awareness, while an alpha reduction results in increased mental activity (Shaw, 1996). The low alpha band (8-10 Hz) is associated with the mechanisms of arousal, attention and effort as well as general cognitive processing while high alpha (11-13 Hz) selectively acts according to the encoding of the stimulus (Klimesch, Schimke, & Pfurtscheller, 1993).

Sports performance has also been shown to improve when implementing hypnotic techniques using flow state suggestions (Lindsay, Maynard, & Thomas, 2005; Baer, 1980; Liggett, 2000). It is not yet understood how hypnosis increases performance or the experience of flow. One suggestion by Crawford and Gruzelier (1992) is a shift made from an analytical thinking style to become more holistic after hypnosis, allowing processes relevant to athletic performance. Hypnosis has been shown to facilitate a movement to right hemispheric activity (holistic, nonverbal, imaginative side functions) from the left (analytical verbal functions) (Gruzelier & Warren, 1993). It has been further shown that there are strong correlations between hypnosis with absorption (Tellegen & Atkinson, 1974). A correlation has also been shown between absorption and dissociation, in which the ability to become absorbed in a task is another way to induce dissociative control (Frischholz, Schwartz, Braun, & Sachs, 1991). Task absorption and dissociation are considered key component to the higher levels of the flow phenomenology.

Additionally, theta activity has been shown as relevant for evaluating cognitive processing during flow like tasks such as meditation . In Lutz et al. (2009) experienced meditators and novices were tested at the beginning and end of a three-month meditation retreat, using an attentional blink test. Experienced meditators results significantly improved whilst presenting increased theta phase-locking, i.e. a reduced variability of theta phases across trials. These results are considered to show a more stable execution of neural processing (Jacobs, Kahana, Ekstrom, & Fried, 2007). Furthermore, multiple fMRI studies have highlighted attentional networks providing support for an increased activation of prefrontal networks during focused (Raz & Buhle, 2006), meditation-like attention (Newberg & Iversen, 2003).

Positive affect and motivational orientation, two elements associated with flow phenomenology, have also found links to changes in frontal EEG asymmetry (Miller & Tomarken, 2001). In particular, higher left alpha frontal activation was associated with approach-related motivation (Pizzagalli, Sherwood, Henriques, & Davidson, 2005). This is also shown by higher activity of the frontal left correlated with activating trait measures of behavioral (Coan & Allen, 2004). Specifically, positive emotions were correlated with increased left frontal activation, while a higher right frontal activation was correlated with negative emotions (Davidson, 2004). Ultimately a relationship between frontal EEG asymmetry for motivational direction and affective valence is shown for performance settings.

1.2.7 Flow facilitation

This collection of results begins to show support for a particular neurocognitive understanding with elements to consider such as a reduction of left frontal activity resulting in higher levels of performance. To further test the neurocognitive mechanisms of different states and in particular flow states, technologies such as transcranial direct current stimulation (tDCS) have been utilized to provide a clearer understanding on the underlying processes. TDCS is a non-invasive form of brain stimulation that alters cortical excitability based on the direction of current flow at subthreshold levels of the neuronal membrane potential. Anodal stimulation has been shown to increase cortical excitability over the region of electrode placement, while cathodal stimulation inhibits the region's neuronal excitability. The level of neuronal activity modulation depends on the current density, which is governed by elements such as current strength and electrode variability. Furthermore, the length of after-effects is dependent on stimulation duration. i.e. excitability effects have been shown to last up to 60min (Nitsche and Paulus, 2001), yet results have also shown effects fading after 30min of stimulation (Iyer et al., 2005).

While tDCS has been used for clinical settings such as depression, Parkinson's disease and pain management, it has also shown to improve performance in normal participants including working memory (Brunoni & Vanderhasselt, 2014), visuo-motor learning (Ammann, Spampinato, & Márquez-Ruiz, 2016), and categorical learning (Gibson et al., 2020). Many experimental paradigms have been implemented on motor learning including the more frequently used skill acquisition and adaptation (Shadmehr & Wise, 2005). Acquiring new motor skills relies on the capacity to execute new motor abilities that improve performance beyond previous levels. Skill acquisition can take weeks or months while skill can decrease due to a lack of ongoing practice. Techniques which improve skill acquisition and retention can be of use to scientific and practical applications. For instance, Clark et al. (2012) showed a unique use of anodal tDCS over parietal and frontal regions for improving skill acquisition speeds by enhancing performance in threat detection within natural scenes that are typically relevant for skills management throughout our specialized and daily activities.

Adaptation for sensorimotor tasks, unlike skill acquisition, addresses a new framework of well learned movements and spatial goals instead of requiring new capabilities of muscle activations to be updated. While adaptation can be assisted with explicit control processes, it can also update entirely implicitly (Mazzoni & Krakauer, 2006). Functionally, adaptation focusses on an error decrease by changing challenge levels to facilitate a return to the previous level of performance, while participants movements are updated due to changes in motor outputs or sensory inputs. TDCS has been shown specifically to enhance adaptation of real world cognitive multi-tasks by specifically targeting the goal-directed dorsal attention network by right parietal anodal stimulation and thereby resulting in improved task performance (Scheldrup et al., 2014). It is important to acknowledge that tDCS has been shown to result in ceiling effects for experts compared to novice performers in which at a certain level of expertise, tDCS has been shown to not have a significant impact on performance (Bullard et al., 2011; Tseng et al., 2012; Furuya et al., 2014; Rosen et al., 2016).

More recently tDCS has begun to be implemented to explore its potential role in facilitating flow. In a recent study, Ulrich et al. (2018) facilitated higher flow scores for people experiencing low flow after stimulating them during an arithmetic task with a prefrontal (Fpz) anodal tDCS to target the medial prefrontal cortex (MPFC). This is an interesting result as Ulrich, Keller, and Grön (2016) showed support for the THH with a deactivation of MPFC during an fMRI study on flow, yet only the excitatory anodal tDCS over the prefrontal regions resulted in an enhancement toward flow states. This was uniquely for people specifically experiencing low flow and therefore more research is needed for the general population. Nonetheless, we see here an introduction into the facilitative role of tDCS experience enhancement that can potentially improve people's skill level in order that the participant could reach the skill-challenge balance (Scheldrup et al., 2014) that allows for a greater movement into flow states (Zhu et al., 2015).

1.3 Thesis Structure

This submission will present in the format for graduation via publication broken up into 8 chapters that aim to investigate flow states in 2 parts, it's cognitive and neurocognitive correlates as well as the impact of neuromodulation technology in inducing flow. Chapter 1 provides a submitted literature review that gives an overview of the thesis structure and an introduction to the flow states and the neurocognitive mechanisms. Chapter 2 provides a submitted literature review of flow's two major neurocognitive theories of hypofrontality and network synchronization, analyzing all the neuroimaging and psychophysiological studies that exist to further identify and clarify the current neurocognitive understandings in flow state research. This paper then further expands on the existing literature to introduce a new potential neurocognitive model to help bridge the similarities and differences found in the competing theories for how flow may be facilitated by the brain. Chapter 3 outlines the research questions and hypotheses of this thesis. Chapter 4 includes the research design, methodology, and analysis techniques of the experiments in this thesis. Chapter 5 begins part one by exploring the cognitive approaches that complement the predisposition towards flow states. Specifically, this third publication aimed to investigate the different cognitive and personality strategies people are predisposed to using during flow tasks in occupational and recreational settings. Furthermore, the extent to which mindfulness mediates the relationship between personality factors (need for cognition and active coping strategies) and the experience of flow states was examined across recreational and occupational contexts.

Chapter 6 begins part two of the thesis by considering the different approach of occupational and recreational flow through the participation frequency component of novice and expert video gamers by testing the modulatory impact of tDCS on cognitive performance and its ability to explore the neurocognitive model of flow states. Specifically, the fourth paper looks at the impact tDCS has on improving processing speeds and learning using a typical occlusion task in a digital sport environment in order to better understand the role of brain stimulation on domain-general performance to inform the use of tDCS for flow tasks. Chapter 7 presents the fifth publication which explores the impact tDCS can have in the facilitation of the subjective experience of flow states across flow tasks for novice and expert video gamers. Chapter 8 finishes with a discussion that aims to identify and then integrate the overall findings of the studies to determine key implications regarding neurocognitive theories of flow states and guide future directions of the research. Additionally, the discussion highlights the thesis's overall limitations of the research findings as well as, academic contributions, managerial implications and the final conclusion.

Chapter No.	**Chapter Title**	**Publication**
Chapter 1	Introduction	A review on the role of the neuroscience of flow states in the modern world
Chapter 2	Literature Review	A neurocognitive model of flow states and the role of cerebellar internal models
Chapter 3	Research Questions	
Chapter 4	Methodology	

Chapter 5	Results	The mediating role of mindfulness in explaining individual differences in flow during recreation and work
Chapter 6	Results	Impacts of transcranial stimulation on sports occlusion task and its frequency power profile
Chapter 7	Results	A Transcranial Stimulation Intervention to Support Flow State Induction.
Chapter 8	Discussion	

Table 1.2: Thesis structure

Chapter 2: Literature Review of Neurocognition of Flow States.

2.1 Publication 2: Rationale

This chapter provides a literature review on the current neurocognitive models of flow states by providing an introduction to flow research and the principle neurocognitive theories that are guiding the research. Additionally, the research focusses on the broad use of neuroimaging technologies to measure and explore flow states and the principle flow neurocomponentry that have been identified and guide the current direction of research. Upon an exploration of these flow theories and the neurocognitive research that has been generated from them, this chapter aimed to identify a new neurocognitive model that works to integrate the existing neurocognitive flow theories as well as extend upon the current body of research to further explain key neural underpinnings and functions of flow states. Submitted paper 2 is included in this chapter.

While this paper has not been accepted for publication yet, it has been peer reviewed and provided with helpful comments. The reviewers' comments were addressed in the following paper which can be found in Appendix 2.

Gold, J. and Ciorciari, J. (2020) A neurocognitive model of flow states and the role of cerebellar internal models. Behavioural Brain Research, (Submitted July 2020)

2.2 Publication 2: A neurocognitive model of flow states and the role of cerebellar internal models.

2.2.1 Flow Introduction

The scientific community has begun to explore the field of optimal cognitive functioning and its physiological components. One area growing in interest is a state of acute focus known as a flow state in which the person experiences the task effortlessly. In this modern context, rich with distractions it is important to help people be able to enhance their ability to focus and improve their performance in any task they are undertaking. Csikszentmihalyi (1975) first described this flow state noting the key antecedents to enter an experiential flow state as a subjective assessment matching a person's perceived challenges or action opportunities with their perceived skill. Additional antecedents were defined as requiring well defined goals of the task and clear, immediate feedback about their progress. This affords a sense of control over reality by understanding what needs to be done and how they are performing (Csikszentmihalyi, 1990). Flow later was elaborated on as a holistic state of optimal performance denoted by smooth and accurate performance with an acute absorption in the task to the point of time dissociation and self-dissociative tendencies (Nakamura & Csikszentmihalyi, 2002).

Flow is considered a psychological state occurring during a task that is experienced as effortless and enjoyable with a heightened focus yet low self-awareness. Furthermore, the task is challenging but matched to the individual's skill level (Csikszentmihalyi, 1990). It also considered that flow requires a skill to be controlled primarily as an implicit function of automaticity in which the individual is unaware of executing their action (Šimleša, Guegan, Blanchard, Tarpin-Bernard, & Buisine, 2018). It has been reported that people in a flow state experience a modified state of consciousness, with an elevated level of absorption and transcendent sense of self, as well as a variation in elements of consciousness characterized by automaticity, distortion of time and acute focus (Csikszentmihalyi, 1997). Flow has been researched across a wide range of activities, including sport (Jackson, 1996), gambling (Trivedi & Teichert, 2017), skateboarding (Seifert & Hedderson, 2010), and education (Rogatko, 2009). People consistently report it in similar phenomenological terms across activities and all were considered autotelic with an intrinsic motivation (Csikszentmihalyi, Abuhamdeh, & Nakamura, 2005). Due to the remarkable similarity explained across such varying fields, it has been proposed that there may be a common underlying neurocognitive pattern resulting in the flow experience.

Flow proneness has been shown to occur regardless of general intelligence but rather it is assumed that flow results from a highly well-defined skill set and therefore more related to expertise (Ullén et al., 2012). People predisposed to flow have also shown a possible neurobiological connection link associated with the intrinsic motivation in the autotelic personality (de Manzano et al., 2013). Csikszentmihalyi (1990) challenges/ skill flow cycle (see Figure 1), as a person increases their expertise or skill in a task, the challenge of the task needs to increase to match the level of skill in order to enter a flow state. Thereby the person is experiencing a high level of arousal and at the same time an experience of high ability. Experts are expected to have more automaticity available as the implicit system requires a series of specialized and independent response patterns to output, free from buffering other information in a higher order representation (Masters, 1992). Flow is considered to increase in intensity on the continuum of experiential quality of the activity as the participant learns to automatize and hence utilize more of their dedicated facilities required for the task (Csikszentmihalyi, 1990).

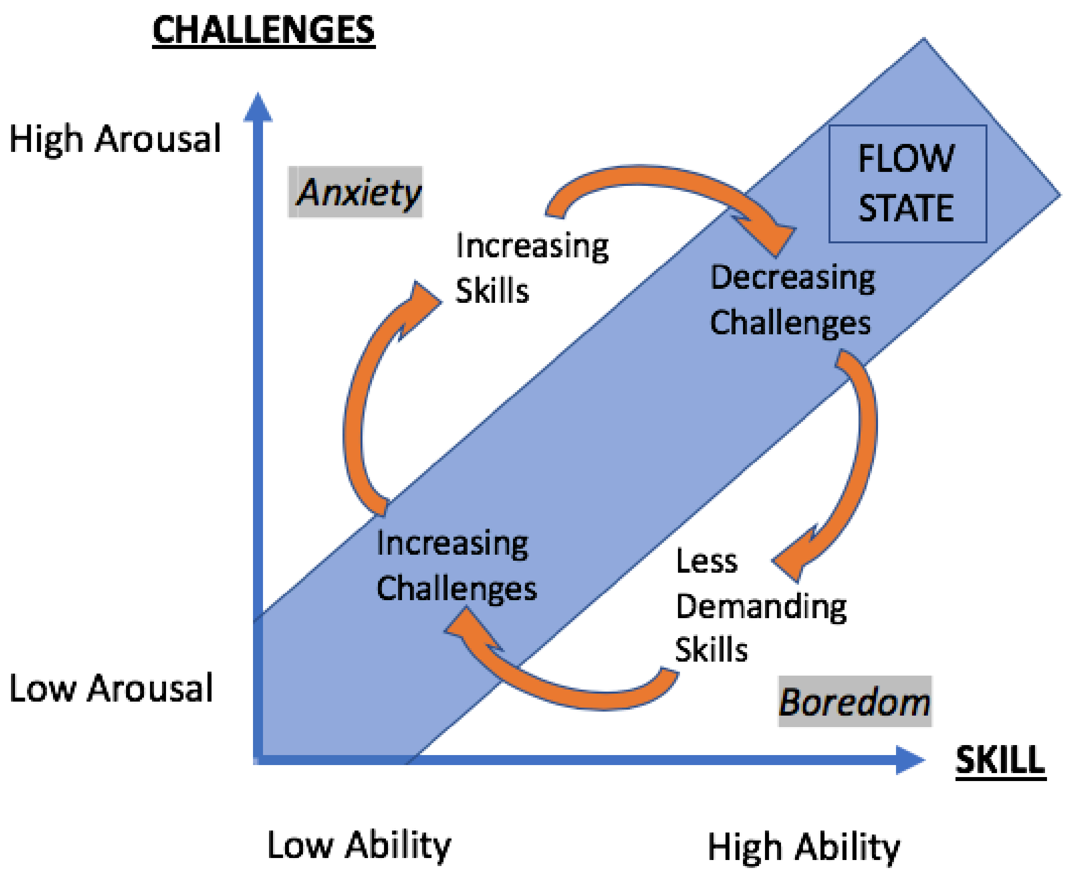

Figure 2.1: Challenges/ Skill Flow cycle adapted from (M. Csikszentmihalyi, 1990)

The principal instrument to study flow states are questionnaires and interviews to probe the subjective experience after the flow task however, these are retrospective by nature rather than concurrent within the task (Swann, 2016). Additionally, these measures have tested flow either as a discrete state or along a continuum measuring flow’s changing level of intensity (Weber, Tamborini, Westcott-Baker, & Kantor, 2009). Flow states are considered completely immersive; thus, void of self-referential thoughts and hence questionnaires force the participant to leave the state. Flow studies have since begun to address this limitation through the use of psychophysiological methodologies, such as electrocardiography (ECG), electromyography (EMG) and skin conductance, which measure the manifestation of psychophysiological phenomena in the body, to explore the dynamic nature of flow experience throughout the entire task (Peifer, 2012).

More recently electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are shedding new light on the neurocognitive elements of flow states. However, there is a lack of unison in these studies in forming a common field of understanding, as they address flow states from different methodological backgrounds and thus different motivations resulting in differing perspectives. Therefore, during this exploratory phase of this burgeoning field, precise research questions are still ill-defined due to the disparate results and difficulty to delineate specific neurocognitive markers. This paper aims to collate and highlight a comprehensive body of neurocognitive knowledge of flow states that will provide a platform for researchers to use as a future reference for hypothesis generation. In the following sections we aim to conceptualize the neurocognitive concepts underpinning flow’s purported functioning described through the two competing neurocognitive model: The transient hypofrontality hypothesis and the synchronization theory of flow. An alternative neurocognitive model of flow based on the internal models, developed and implemented, via the cerebellum is then presented as a way to unify these two pre-existing models by highlighting the similarities whilst explaining the differences through the functional role of cerebellar internal models. Finally, we offer the most promising directions for future research in order that flow may more effectively be utilized to enhance task effectiveness across the gamut of human activities.

2.2.2 Transient hypofrontality hypothesis

2.2.2.1 Hypofrontality

Originally, flow was presented as a movement toward the most efficient output of optimal functioning, as Csikszentmihalyi (1990) postulated an inhibition of mental activity irrelevant to the task. Dietrich (2004) built on this to propose the transient hypofrontality hypothesis (THH) for flow as a state of transient downregulation of the prefrontal cortices, defining flow processes in the form of explicit and implicit information-processing systems. The THH describes flow as requiring the full support of the implicit and automatic systems to execute a task at optimal output i.e. “maximum skill/ maximum efficiency”, while the majority of the cognitive functions of the prefrontal areas are inhibited (Dietrich, 2003). These implicit systems automate functioning via the basal ganglia (BG) and are hence considered offline to conscious modification, containing skills and experiences that cannot be verbalized, yet still observable during the task. This implicit performance system is considered to process efficiently and quickly in a definite context due to its freedom from buffering extraneous higher order cognitive components (Dietrich & Stoll, 2010). Flow states are therefore considered to be processed primarily as a reflexive system, guided by the preceding input, allowing it to provide a maximal output in the moment (Dietrich, 2004). In summary, the THH places major emphasis on two principal functional changes for the induction of flow states. First, the inhibitory process of the prefrontal cortices that frees up a computational bottleneck of the explicit systems and secondly, a focus on automatization of action through greater control of implicit systems contained in the BG.

Several EEG flow studies implementing retrospective flow questionnaires have been able to show THH support for flow tasks such as shooting (Bertollo, 2014), arithmetic (Katahira et al., 2018), video games (Castellar, Antons, Marinazzo, & Van Looy, 2019) and memory tasks (Fairclough, 2008) as well as near-infrared spectroscopy (fNIRS) studies performed by Katayose, Nagata, and Kazai (2006) on people listening to music and Hirao (2014) using a verbal fluency test on occupational therapy students. While these studies were able to show a prefrontal deactivation, many of these studies lack sufficient electrode numbers such as Castellar et al. (2019) limiting the report of recording to the midline channels of Fz, FCz and Cz, and the fNIRS studies testing only testing frontal channels Fp1/2 (Hirao, 2014).

More recently, fMRI flow studies testing mathematical tasks found a reduction in prefrontal regions (de Sampaio Barros, Araújo-Moreira, Trevelin, & Radel, 2018; Ulrich, Keller, & Grön, 2016b; Ulrich, Keller, Hoenig, Waller, & Grön, 2014; Ulrich et al., 2018). This hypofrontality revealed a reduction in the medial prefrontal cortex (mPFC), which has been associated with self-monitoring and reflective processing employed during explicit processes shown to limit the efficiency of the system (Shiffrin & Schneider, 1977; Yarrow, 2009). Along with the reduction of mPFC, additional components also associated with the default mode network (DMN) showed reduced activity in these flow studies, including the amygdala and angular gyrus (Ulrich, Keller, & Grön, 2016a; Ulrich et al., 2016b; Ulrich et al., 2014). Goldberg, Harel, and Malach (2006) describes the DMN as a global resource allocation network that shows higher activity across resting states than goal-directed behaviors. The DMN works to reduce task irrelevant processes such as self-referential activity, thereby freeing up implicit processes through reductions in explicit self-analytical processes (Andrews-Hanna, 2011).

The DMN has been considered to facilitate a major role in consciousness processes (Raichle, 1998), in which reductions have also been shown in other altered states of consciousness similar to flow including meditation (Garrison, Zeffiro, Scheinost, Constable, & Brewer, 2015) and psychedelics research (Carhart-Harris et al., 2012). The DMN neural components is considered to have one of the highest cortico-cortical connections and in particular, the reduction of amygdala and mPFC activity revealed in these flow studies have also been associated with introspective thoughts (Philippi, Duff, Denburg, Tranel, & Rudrauf, 2012) and emotional arousal (Colibazzi et al., 2010) which are critical to the activation of flow (Peifer, 2012) due to their roles in undistracted focus of the task and autotelic reward, respectively.

2.2.2.2 THH and reduced self-monitoring

Csikszentmihalyi et al. (2005) conceptualized flow states as a low level of internal verbal thought, which is mirrored by THH's emphasis on implicit functions supported through reduced verbal-analytical involvement. This reduction of self-monitoring encourages reduced reliance on working memory (Masters, 1992), enabling performance with higher neural efficiency than explicit functions dependent on working memory such as during motor tasks (Zhu et al., 2015). This is further supported by increased left temporal alpha activity showed improved performance in experts from a reduction in cortical activations due to reduced verbal-analytic processes, thus more resources allocated to right hemispheric visual-spatial processes (Vernon, 2005). The left temporal region includes several relevant structures of the brain related to flow, including Wernicke's area which is involved in the comprehension of language. These neurocognitive patterns are considered helpful for researching psychophysiological states during skilled motor performance, in which the left temporal region was shown to be relevant for expert performance, with increased alpha power occurring for expert marksmen compared with novices (Lawton, Hung, Saarela, & Hatfield, 1998). This alpha pattern has also been identified across a range of activities from weight lifting (Gannon, Landers, Kubitz, Salazar, & Petruizello, 1992) to golf (Crews & Landers, 1993).

A driving study on peak performance by Kramer (2007), developed a paradigm to emulate flow experiences by utilizing the three flow antecedents (clear goals, feedback and skills/ challenge balance) and found increased alpha of the left temporal region compared to the right. This study however only tested the temporal regions and did not question for flow states specifically in the study. More recently, a brain-computer interface study (Berta, Bellotti, De Gloria, Pranantha, & Schatten, 2013) was able to differentiate between flow states in the alpha, low-beta and mid-beta bands using a total spectral analysis of bi-hemispheric frontal and temporal locations. While the measures were averaged across all the electrodes it does highlight the importance of the alpha and beta frequencies for the frontal and temporal regions. Another flow study (Wolf et al., 2015) also demonstrated an alpha desynchronization over the left temporal lobe associated with decreased influence over verbal analytic processing for motor control during an imagined table tennis scenario. This was supported by Hatfield, Landers, and Ray (1984), who demonstrated skilled marksmen had a lower temporo-frontal coherence which related to a reduction of extraneous cognitive influence on motor processes.

Lower coherence estimates between left temporal and motor regions has also shown similar functional relatedness to left temporal deactivation (Deeny, Hillman, Janelle, & Hatfield, 2003). A flow study by Yun, Doh, Carrus, Wu, and Shimojo (2017) showed a similar coherence pattern of reduced verbal-analytic influence over motor control areas during a first person shooter video game but did not differentiate hemispheric asymmetries to localize specifically the left temporal influence. These patterns, nonetheless, denote less cortico-cortical communication and a suppression of analytic processing, thus simplifying a complex process and alleviating the need for a division of cognitive resources to support more streamlined processes associated with the implicit function of flow.

2.2.2.3 THH and cognitive control

Goal-directed top-down control was further supported by the current body of flow studies that identified both the activation of the dorsal attention system and the deactivation of the ventral attention system associated with stimulus driven bottom-up processes. Ulrich et al. (2014) and Ulrich et al. (2016b) tested flow using a math task to find similar areas activated with the multiple demand system, which overlaps with the frontoparietal dorsal stream that enables the ability to engage in goal-directed behaviors, solve novel problems, and acquire new skills (Duncan, 2013). Recently, increases in the functional connectivity of the frontoparietal network from transcranial stimulation has shown improvements in information flow and performance (Hunter et al., 2015; Violante et al., 2017). More specifically, a transcranial direct current stimulation (tDCS) flow study by Gold and Ciorciari (2019) showed support for flow state induction by utilizing the frontoparietal network with a 2mA frontal left cathode and a right parietal anode stimulation.

Ulrich et al. (2014) and Ulrich et al. (2016b) also showed reductions in key areas along the ventral attentional system along with Klasen, Weber, Kircher, Mathiak, and Mathiak (2012) who also showed a reduction in the temporoparietal junction (TPJ) during the focused attention component of their flow study with video games. This pattern has also been seen in improvisation studies, often associated with similarities of flow, in which experts in music (Berkowitz & Ansari, 2010) and dance (Fink, Graif, & Neubauer, 2009) showed a reduction in TPJ considered to denote the ability to stay focused during a task compared to novices. This inhibition of bottom-up processes is considered to arise from top-down activations to prevent reorienting of attention to task-irrelevant salient stimuli, thus detracting from task performance (Corbetta, Patel, & Shulman, 2008) and thus the ability to maintain focus long enough to enter into flow states.

Katahira et al. (2018) recently replicated Ulrich et al. (2014) arithmetic flow study to find a lack of THH support by reporting an increase in frontal midline theta which has been associated with higher levels of cognitive control due to focused attention towards a goal (Brown, 2013). This contradicts ideas assumed by THH as initiating explicit thought towards a task that has been transferred to function implicitly would result in a reduction in performance (Beilock & Carr, 2005). Therefore, it is expected to not see an increase in cognitive control as “effortless attention is an inherent function of superior performance” (Dietrich & Stoll, 2010). Several other flow studies have also shown frontal theta activity which also support the activation of top-down goal-directed processes (De Kock, 2014; Fairclough, Gilleade, Ewing, & Roberts, 2013; Katahira et al., 2018; Nacke, Stellmach, & Lindley, 2010; Wolf et al., 2015).

Top-down processes of frontal midline theta has more commonly been attributed to its generation from the anterior cingulate cortex (ACC) (Brown, 2013). Inversely, an ACC inhibition has been shown to represent a sense of effortlessness as reported by Naccache et al. (2005) during a Stroop task by a patient with an ACC lesion, regardless of normal executive control. Flow states are described with a heightened sense of control and a lack of effort, which has found support from reduced ACC activity demonstrated in all fMRI flow studies (Klasen et al., 2012; Ulrich et al., 2016b; Ulrich et al., 2014) but one in which Ferrell, Beach, Szeverenyi, Krch, and Fernhall (2006) measured flow using a hypnotic induction that required the participant to visualize the flow state and thereby didn't require any immediate action or effort.

2.2.2.4 THH and Basal Ganglia

The second focus of Dietrich (2004) THH is the shift towards an automatization of action through greater control of implicit systems contained in the BG. Learning of automated responses takes time because of the limited ability of the explicit working memory to transfer specialized and reflexive response patterns to the implicit system due to capacity restrictions (Rauch et al., 1997). Whilst the neural substrates are less clear for the implicit system, the BG has most often been critically associated with the implicit system (Poldrack & Packard, 2003). The BG is believed to be a passive observer during this time, building its own representation of the action (Gazzaniga, Ivry, & Mangun, 1988). After sufficient practice, neural control is gradually shifted to the BG (Mishkin, Malamut, & Bachevalier, 1984) and also the supplementary motor area (SMA), the hippocampus, and the thalamus (Jenkins, Brooks, Nixon, Frackowiak, & Passingham, 1994). The BG is considered to then be the primary operator of the action, with support from the parietal and SMA (Jankowski, Scheef, Hüppe, & Boecker, 2009).

Every fMRI flow study including Ulrich et al. (2014), Klasen et al. (2012) Ulrich et al. (2016b), Ferrell et al. (2006), as well as striatal dopamine tests by de Manzano et al. (2013) and Gyurkovics et al. (2016) have all lent support to the influential role of the BG in flow state induction by showing an activation of both the putamen and the ventral caudate nucleus in the dorsal striatum during flow states compared to controls. The striatum is considered to be a related structure for implicit learning, in which its volume was positively correlated with the video game skill acquisition during a training task (Erickson et al., 2010). The putamen has been shown specifically related to assessing goal-directed behavior in relation to challenge (Hori, Minamimoto, & Kimura, 2009).

Furthermore, the caudate nucleus has been identified as a primary input structure of the implicit system (Ashby, Ennis, & Spiering, 2007). The caudate nucleus has also been associated with virtual presence and has been suggested to be associated with the emergence of flow and its deep immersive states (Baumgartner et al., 2008; Klasen et al., 2012).

2.2.2.5 THH criticisms

This overall collection of THH findings highlights a reduction of explicit verbal-analytic influence from left frontal and temporal regions resulting in higher levels of performance and a movement toward implicit function governed by striatal activations. However, the THH has had its share of critics in which it's believed to oversimplify the operationalization of flow experiences (Weber et al., 2009). Peifer (2012) contrasted flow states with meditation studies, considering it a state of altered consciousness in which people experience similar elements to that of flow including intrinsic motivation, time distortion, states of elation, self-transcendence etc. Hundreds of studies have now been done on meditation making it a well-studied area, and possibly help inform some of the neural underpinnings of flow states (Boccia, Piccardi, & Guariglia, 2015). Multiple fMRI studies have shown support for increased, instead of reduced, prefrontal network activity during states of focused, meditation-like attention (Newberg & Iversen, 2003; Raz & Buhle, 2006) and a form of meditation known as mindfulness has even been used as an intervention to promote flow (Chen, Tsai, Lin, Chen, & Chen, 2019). More recently, there has been a recent spate of flow studies reporting a lack of support for THH, with increases in frontal high beta activation described in multiple flow studies including an academic learning task (Wang & Hsu, 2014), Tetris (Harmat et al., 2015; Yoshida et al., 2014) and a racing game (De Kock, 2014).

2.2.3 The synchronization theory of flow

2.2.3.1 Synchronization

The THH has been contrasted with Weber et al.'s, (2009) synchronization theory of flow (STF), that describes flow as a “holistic, higher-order experiences that is ill explained by isolated traits of those experiences”. STF states that synchronization of neural activity enables large scale integration, due to neural binding, across many parallel processes (Buzsáki & Draguhn, 2004) resulting in in “whole-brain” work (Başar, Başar-Eroglu, Karakaş, & Schürmann, 2001). STF draws primarily on the alerting and orienting responses of Posner (1986) tripartite theory of attention to suggest the experience of flow arises from the synchronization of both the neural networks of focused attention and secondly the coordinated firing of the reward networks associated with intrinsic motivation resulting in pleasurable experiences associated with flow.

Synchronization between neural regions is considered to be indicative of neural bindings, where signals transmitting in a similar pattern between two associated regions indicates a relation to the same function (Engel, Fries, & Singer, 2001). In particular, these neural bonds form functional networks allowing the brain’s key areas to carry out their tasks. Large-scale neural synchronization has further been presented as an energetically cheap state of consciousness (Buzsáki, 2006) and has since been evidenced using a global efficiency score in Huskey, Wilcox, and Weber (2018) to help explain why flow is considered as pleasurable rather than energetically taxing (Huskey, Craighead, Miller, & Weber, 2018). Therefore, during flow, specific attentional and reward networks are expected to synchronize in a hebbian manner (Weber et al., 2009).

EEG coherence studies have shown that synchronized neural groups during the coding of sensory data triggered adaptive motor performances such that increased coherence has been associated with the task requirements of visuomotor integration (Engel et al., 2001). Coherence results in flow studies that support STF include Wolf et al. (2015), who found a stronger theta cortico-cortical communication between right temporal and premotor cortex in a table-tennis imaging task,. Yun et al. (2017) also showed in their flow study a top-down connectivity from ACC to the temporal pole and then motor cortices. These results denote an emphasis on implicit functioning compared to expertise studies which tend to be associated with the explicit prefrontal areas (Engel et al., 2001).

2.2.3.2 STF and cognitive control

Yun et al. (2017) showed a further whole brain suppression, originally proposed by Weber and Huskey (2013), in which an irrelevant secondary task such as an auditory evoked response was found to be delayed for people in flow compared to non-flow trials. The non-linear attentional saturation hypothesis was empirically tested by Weber, Alicea, Huskey, and Mathiak (2018) to further support the idea that greater synchronization of attentional networks, afforded by connectivity, happens at critically reduced levels of distraction. Taken together this suggests that during flow, brains free themselves from distraction of task irrelevant stimuli as they move into flow states. This flow suppression was further supported in Castellar et al. (2019) who showed an increased delay in responses associated with the pre-motor/ supplementary motor area (SMA), typically associated with monitoring and managing motor functions (Asemi, Ramaseshan, Burgess, Diwadkar, & Bressler, 2015). This pattern appears to lend support to the deactivation of the salience driven ventral attention network and further provide support for the role of increased top-down modulation of the dorsal attention stream during flow states influencing whole brain functioning.

Additional top-down activation has shown to support STF in de Sampaio Barros et al. (2018) fNIRS study on flow using videogames, in which a strong activation of the lateral frontoparietal network during flow conditions was shown compared to difficult and easy videogame conditions. This research was further supported by an fMRI video game study performed by both Huskey, Wilcox, et al. (2018) and Huskey, Craighead, et al. (2018) who further identified a reward structure, the nucleus accumbens, directly connecting to the frontoparietal region during flow states. These key implications of the relevance of cognitive control as a key component in flow states is ultimately shown through the strong correlation of flow states with the attentional and reward neuronal network. This is similar to patterns presented in the THH research, showing not only a mobilization of top-down attentional resources during flow, but also a promotion of autonomy through intrinsic rewards.

2.2.3.3 STF and Basal Ganglia

The switching between non-synchronizing to synchronized states is considered to be initiated by the striatum. For example, animal studies have lent support that attention and the experience of reward are influenced by neural synchronization (Baldo

& Kelley, 2007). Reward value and direction of actions is also related to neuronal encoding in the primate putamen, in which synchronized activity enables it to efficiently convey information to basal interconnected subnetworks during a well-practiced behavior (Adler, Finkes, Katabi, Prut, & Bergman, 2013). The striatum’s putamen is also related to the evaluation of goal-directed behavior based on dopamine facilitated reward prediction in relation to effort (Hori et al., 2009). Additionally, studies have shown support in the flow literature for STF, such as Klasen et al. (2012) reporting neural system optimizations by segregating flow into individual cognitive elements to find a synchronization of reward structures with task-relevant cortical and cerebellar areas. It was further suggested that flow proneness is associated with the dopaminergic system that processes intrinsic motivation. de Manzano et al.'s (2013) study showed how flow proneness elevated the availability of striatal dopamine D2 receptors and that the level of intrinsic motivation was ultimately related to the number of available receptors within the striatum for dopamine.

The striatum has further been shown to modulate cognitive functions through dopamine regulation such as focusing of attention (Nieoullon, 2002), increase synchronization (Elibol & Sengor, 2015) as well as behaviour inhibition (Congdon, Lesch, & Canli, 2008). Furthermore, a reduction of dopamine D2 receptors has been linked to impulsive behaviour (Simon et al., 2013). Gyurkovics et al. (2016) builds off this to suggest a relationship between striatal D2 dopamine and flow may occur due to lowered impulsive behaviour to downregulate task-irrelevant behaviour that would enable cognitive processing to be more energetically efficient.

Ultimately, the principal assumption shared in both the STF and THH models denotes a focus on mental economy, whether by the use of large scale neural synchronization of attentional systems (Gotts, Chow, & Martin, 2012) or inhibiting the excessive role of frontal activation freeing up cognitive resources from bottlenecking of information processing with analytical associative processes (Hatfield & Hillman, 2001). Furthermore, it can be seen that both models focus on the striatal dopaminergic system that affords greater automatized implicit functioning in conjunction with supporting intrinsic motivation through synchronized reward networks.

2.2.4 Internal model of flow states

2.2.4.1 Cerebellar internal models

While the shared findings of the THH and STF both appear to focus on mental economy and implicit processing alongside synchronized activation of the striatal reward system associated with intrinsic motivation, conflicting evidence also appears to present around differing results both supporting and contradicting hypofrontality as well as the importance of synchronous networks for flow to occur. Such discrepancies open up the possibility for new considerations that may speak to these similarities and discrepancies whilst explaining other key neural functions activated to further create a more comprehensive neurocognitive model of flow states.

It has been shown that the brain makes use of an internal model which provides a sensorimotor representation of oneself with the world around (Jordan, 1996). Internal models overcome the diminished speeds of neural conduction by providing predicted information about future properties of elements within the task to allow for faster interpretations and reactions within the task (Imamizu & Kawato, 2009). As the brain explicitly begins to learn motor or cognitive tasks, cerebellar activity increases and then decreases as the internal model is acquired (Imamizu et al., 2000). The cerebellum has been shown to form an internal model during skill acquisition using generalized error prediction and supervisory learning systems that adjusts as the behavior is executed based on merging reactive reflexes with anticipatory actions (Herreros & Verschure, 2013). Inhibitory signals from the cerebellar nuclei refine behaviors of cerebellar micro-complexes that store models of specific functions, via the input-output relationship of the olivary “error detection” system by comparing the current action with the existing internal model (Ito, 2006). This error detection system has been shown to move the system towards optimality by minimizing cost rather than error through balancing anticipation and reaction (Brandi, Herreros, & Verschure, 2014). As an incongruence forms between behavior and the internal model, cortical feedback signals are sent through the parvocellular red nucleus to the inferior olivary system to code the error and transmit corrections via the climbing fiber system to adjust the model (Reid et al., 2009). Through practice and repetition, this model is refined so the behavior can be performed increasingly efficiently and economically, without the need for conscious control. Thereby explaining how we can move with more skill through ongoing practice.

2.2.4.2 Internal models and cognitive control

An internal model is formed in the cerebellum through a learning process that acts as "a system that mimics the behavior of a natural process" (Wolpert & Kawato, 1998). Multiple internal models are considered to exist, and as they learn new environments and tools, localize the new activity to a specific region of the cerebellum (Imamizu et al., 2000). There are two types of internal models: forward and inverse models. Forward models determine the causal relationship between the input (such as motor command of the arm) and predicts the outcome of the next state the movement will generate (such as the position of the arm) (Kawato, Furukawa, & Suzuki, 1987). Inverse models, on the other hand, will invert this system by determining the motor command required to cause the desired state change (such as the desired position of the arm). Many of our automatic everyday processes utilize inverse model processes so that environmental changes can in turn be modified by updated forward models and their interaction with inverse models (Wolpert & Kawato, 1998). Forward and inverse models have been shown to not only be utilized for movement but also to explain the role of implicit processing by identifying the role of the network connecting the cerebellum, parietal and frontal regions to explain this control of high level processes such as decision making (Deverett, Koay, Oostland, & Wang, 2018; Ito, 2008). This cerebellar predictive processing relevant for motor, sensory and cognitive behaviour is mirrored by anatomical loops sent to all cortical sites, from the cerebellum's dentate nucleus via the thalamus and in turn receives feedback via the pontine nuclei (Ramnani, 2006).

As Ito (2008) explains in both the forward and inverse models, shown in Figure 2b, there first is an input of instructions given to the controller by the instructor, typically associated with the premotor, SMA or ACC. The instructor provides a goal for the system to work toward. The ACC has been contrasted with the pre-SMA as relating actions to their consequences to guide toward decisions worth taking (Nachev, Kennard, & Husain, 2008). Furthermore, as stated earlier, an inhibited ACC has been shown to represent the experience of a reduced sense of effort. The pre-SMA, on the other hand, has been shown to be involved with anticipatory preparation of task control and selection of a task set , while the SMA is considered more directly related to motor output (Nachev, Wydell, O'Neill, Husain, & Kennard, 2007). The SMA and pre-SMA have been shown to receive strong cerebellar projections from motor and associative non-motor regions, respectively (Akkal, Dum, & Strick, 2007). This appears to provide key features necessary for determining the actions required by the instructor of the inverse model during flow states with many flow studies showing activations of the pre-SMA and premotor regions (Ferrell et al., 2006; Klasen et al., 2012; Liu et al., 2012; Ulrich et al., 2016b).

Next depending on whether it's motor or mental activity, the controller, considered to be located in the motor and prefrontal cortices, respectively, converts the instruction into a command. For example, a target, as an instructed spatial position is converted into a command that are the signals in the nerves that activate the muscles. The visual cortex may also modify motor feedback from the body to the motor cortices during a motor task (Suway & Schwartz, 2019). For a mental activity, the prefrontal regions act as the controller to construct the mental model, a psychological framework used to explain and anticipate reality, which is considered related to the temporo-parietal regions (Penfield & Perot, 1963). Ito (2008) has further suggested that based on prior research, mental models can be encoded in the areas and circuits where they are activated. The actioning of the mental model is considered similar to a movement activity’s controlled object which converts a command in lower motor centers into an output action. For example, the muscle converts innervation signals into a contraction. Whereby the actioning of the controlled object, albeit mental or motor activity, is refined in the cerebellum by error learning tuning the forward model and then fed back to the controller in which to carry out the task. Feedback occurs via the prefrontal cortex or the motor and visual cortices for non-motor and motor functions respectively, that are sent to the inferior olive (IO) via the red nucleus (pRN) that modulates the processing within the cerebellum (Burman, Darian-Smith, & Darian-Smith, 2000).

The inverse model, however, is refined using feedback-error learning to supplant the forward model's controller, bypassing the prefrontal region (Chen et al., 2003) or the motor cortex (Schmahmann, 1997), and instead the cerebellum takes on the role as an "implicit" controller of the controlled object. The inverse model's generated action would be experienced as intuitive and effortless as if something else was in control. Either way, as shown in Figure 2a, the internal feedback loop operates separately from a normal sensory feedback loop by running slightly ahead of the action execution, thereby anticipating differences between predicted and intended results and correct them to stop any errors eventuating (Wolpert & Ghahramani, 2000).

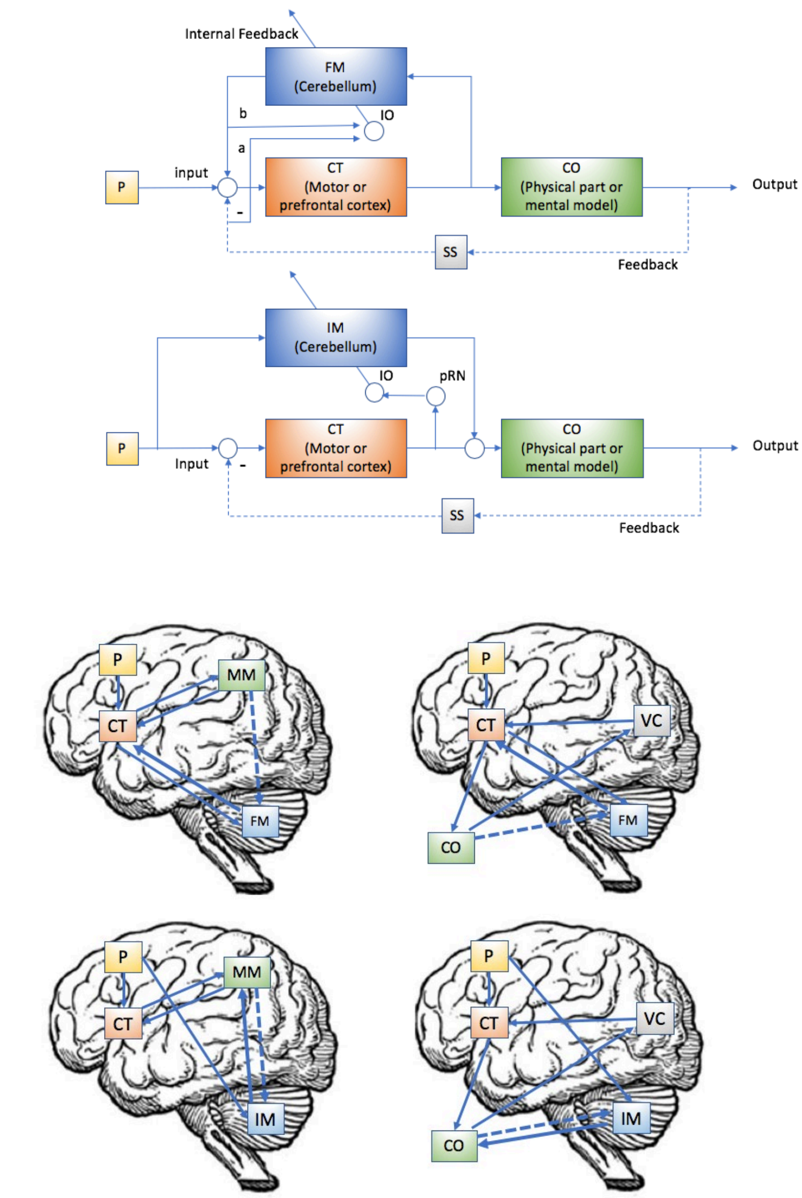

Figure 2.2: Forward and Inverse a) schematic model and b) neurocognitive model of motor and cognitive function adapted from Ito (2008). P- Instructor, CO- Controlled object, MM,- Mental model, CT- Controller, SS- Sensory System, VC- Visual Cortex, IM- Inverse model, FM- Forward model, IO- Inferior olive, pRN- Parvocellular red nucleus

These internal model descriptions align with many of the key qualia of flow states in which the person has both a heightened sense of control and a transcendence of self. By comparing these similarities between the inverse model and flow states, all but one of the fMRI flow studies have revealed activation in the cerebellum. Ferrell et al. (2006) found activation in the cerebellum during a zone inducing hypnosis based visualization task compared to normal activity and resting states. Klasen et al. (2012) also found in the flow conjunction analyses, an activation of the cerebellum as well as Ulrich et al. (2016b) who found cerebellar activity during a math task. The implicit actions of the inverse model that take place out of conscious control still allow for the allocation of resources to be directed to meta-analytic areas in which people have described watching themselves perform the action almost outside of their control. This may also help clarify the dissonance between flow as a discrete state versus the varying level of intensity as well as explaining the partial support for and against the THH of flow due to the feedback role of the prefrontal cortices as a controller. With more prefrontal feedback, this could result in a dampening of the intensity of experienced flow in order to facilitate a more meta-analytic experience brought to the conscious foreground, while a task primarily controlled from the cerebellum through the internal model may allow for a discrete flow experience as an altered state of consciousness.

Additionally, it has been considered that to control and manipulate cognition or movement was equivalent for the brain, and in particular the cerebellum (Bloedel & Bracha, 1997; Ito, 1993). This helps explain why a similar qualia of experience during flow states are continuously described regardless of whether the task is motor or cognitive related. Evolutionarily, it has been argued that the cerebellum evolved before the frontal regions and potentially inherent in instructing this newer frontal region how to predict behavior outcomes through cognitive thought (Koziol, Budding, & Chidekel, 2012). Therefore, the main difference between planning and execution of an action is the execution of the behavior, as thought is considered to have evolved to facilitate motor control (Frank, Loughry, & O'Reilly, 2001). The cerebellum intervenes by identifying predicted patterns of motor or command patterns through sequencing and links them with learned consequences allowing a feed-forward response to be estimated (Molinari et al., 2008). Therefore, it is by sequencing, that the cerebellum can be free from any singular modality of state estimation. A lesion study by Leggio et al. (2008) developed a card set to specifically differentiate among verbal, spatial, and behavioral processes by sequencing them in a logical order. Cognitive impairments in sequencing were attributed to cerebellar lesions in which hemispheric correlations showed decreased performance based on right/ left visual/ verbal differences. This interaction affected only the characteristic of the information and not the mode of function. Thereby, the ability of all functional domains from motor to cognition can assist flow states across its varied tasks through cerebellar influence of inverse models though the facilitation of recognizing sequenced patterns.

2.2.4.3 Internal model and basal ganglia

Functional motor and cognitive tasks are also supported through an interplay of the cortex and multisynaptic loops with the BG and cerebellum [see review (Bostan, Dum, & Strick, 2013)]. From a systems level perspective, a comprehensive framework has begun to address the interconnectivity of the cortex with the cerebellum and BG, to understand their individual functional and learning contributions due to their synchronous activations (Doya, 1999). The role of unsupervised learning via Hebbian learning in the cortex maps the statistical regularities of the observed environment (Hinton, Sejnowski, & Poggio, 1999), while supervised learning via the cerebellum supplies a desired action plan through an internal model by assessing its difference to the current output (Wolpert & Kawato, 1998). Reinforcement learning in the striatum is involved with action selection based on the dopaminergic reward predictions that alters behaviour during the course of the task (Niv, 2009). However, data has indicated that the BG's role may be more involved with integrating ambiguous signals across different modalities and selecting an appropriate action rather than predictive processing (Graybiel, 2000). Reinforcement differs to supervised learning systems of the cerebellum due to its limited feedback, in that it may only communicate a reward or failure, such as falling over when running, while the supervised system can fire moment by moment, such as modifying balance across difficult terrain (Caligiore, Arbib, Miall, & Baldassarre, 2019). An integrated framework may therefore require the striatal-thalamo-cortical loop to perform an abstract search of possible actions and determine an opportune goal based on dopaminergic guided reinforcement learning (Stocco, Lebiere, & Anderson, 2010) and the cerebellar-thalamo-cortical loops to generate signals to maintain and achieve these goals. Both these loops feedback to the same input area of the cortex via the thalamus to create an action and learning/ adaption system (Itō, 2012).

Whilst both cerebellum and BG are shown to be multisensory integration sites working harmoniously for both learning and execution of tasks, their dynamic interplay in conjunction with the thalamus and cortex has traditionally been thought anatomically and functionally segregated. However, more recently studies have begun to reveal functional connections between BG and the cerebellum that support their direct interplay believed to result in successful adaptation of covert and overt movements within the environment (See Figure 3) (Cotterill, 2001). Retrograde transneuronal transport showed both motor and non-motor portions of the cerebellum and BG share bisynaptic pathways to the cerebellar dentate nucleus to the striatum via the thalamus and to the subthalamic nucleus via the pontine nucleus (Milardi et al., 2016). It has been hypothesized that these cerebellar signals may transmit sensory state information to the BG to influence reward-related learning (Bostan et al., 2013) and adaptive motor control and procedural memory through altering striatal plasticity (Chen, Fremont, Arteaga-Bracho, & Khodakhah, 2014). The signals from both the BG and cerebellum may result in a combined action over the controlled object through the distributed processing modules that affords a complete bypass of explicit processes of frontal regions.

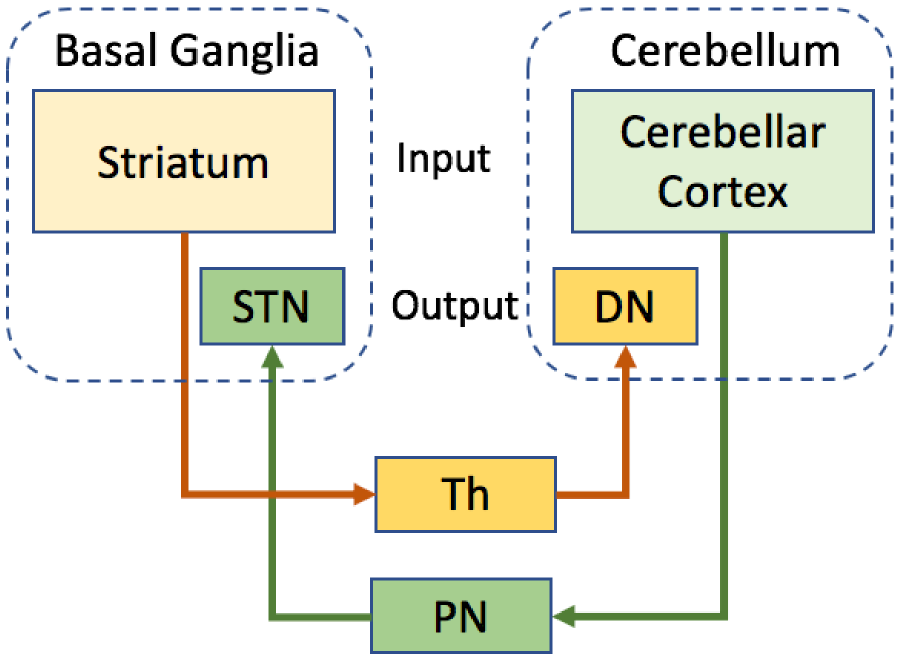

Figure 2.3: Disynaptic connections between cerebellum and basal ganglia. Adapted from (Bostan et al., 2013).

The neurocognitive internal model of flow states assumptions about the integrative functional role of the cerebellum and basal ganglia, as presented in Figure 4, can be summarized as follows: A) The inverse model for motor (blue arrow) and non-motor function (orange arrow): Cerebellum receives instructions from the pre-SMA/ SMA via the pontine nuclei that then sends command signals via the thalamus onto the controlled objects in lower motor centers, or the mental model in the temporo-parietal association cortices. Feedback can modulate the cerebellum from the controller (prefrontal or motor and visual cortices for non-motor and motor functions respectively), sent via the IO/pRN (dotted arrows). B) The cortico-striatal loop is necessary to establish rules through reinforcement learning (black arrows) C) The bi-synaptic cerebellar-striatal loop selects the appropriate information transmitted by the striatum to the cerebellum via the thalamus and the striatum receives information from cerebellum to evaluate for motivational factors (green arrows).

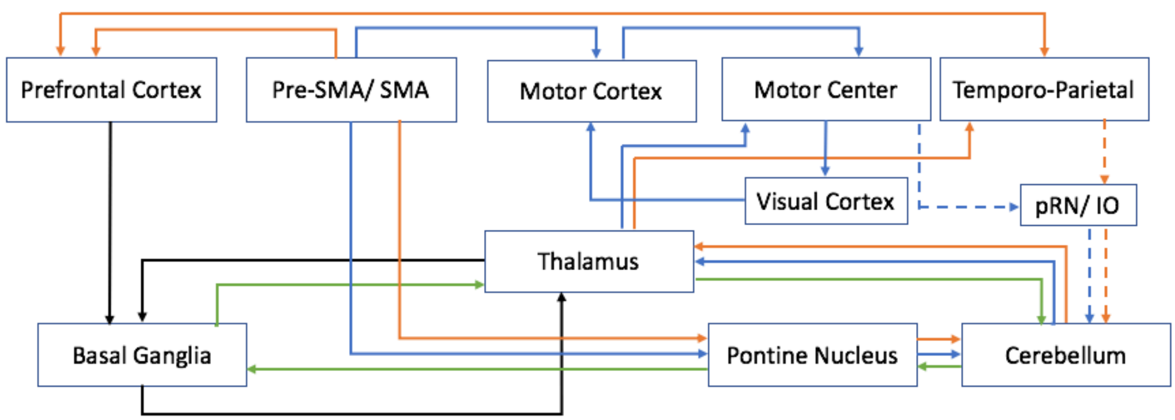

Figure 2.4: Neurocognitive internal model of flow states. SMA- Supplementary motor area, pRN- Parvocellular red nucleus, IO- Inferior olive.

Both the cerebellum and the BG (striatum) receive dopaminergic projections from the midbrain that regulates their activity. These dopaminergic pathways can provide key rewarding and motivational information that transmits stimulus value to the BG (Haber, Fudge, & McFarland, 2000) and plays a role in positive emotional processing via the cerebellum (Blatt, Oblak, & Schmahmann, 2013). Through the dual action of the sensorimotor loop via the dorsal pathway of the visual cortex and parietal cortex, the striatum contributes to the selection of motor patterns of the premotor cortex which corresponds to the specific habits. This goal-directed behaviour is driven through a top-down influence from the cortex on the instructor. Depending on the task the pre-SMA/

SMA will select an appropriate sequence of movements with help from the premotor cortex. The permissive action of disinhibition for a particular sequence will be favored via communication from both the striatum and cerebellum (Cotterill, 2001), however striatal connections dominate with much faster communication compared to the cerebellum receiving nearly four times the connections (Akkal et al., 2007). Therefore, the unique involvement of the basal-striatum connection can be seen in helping to determine the sequence pattern from the pre-SMA instructor in order to play out the specific patterns of the inverse model. These same innervation patterns have been observed in many of the flow studies with both the striatum and the cerebellum present.

2.2.5 Flow integrative model discussion

From the research, two shared themes have become evident in the two foundational models: 1) An enhanced attentional component through a focus on implicit processes and 2) A positive reward-based motivation system associated with striatal dopaminergic influence. While both the THH and the STF lack comprehensive support, when considered with the addition of the internal model, an expansive understanding forms from the contributions of all three models to highlight key features and functions that culminate in a novel state that is a) goal-directed b) automatized, implicit function that c) frees the systems from both external stimulus, as well as verbal-analytic distractions by utilizing d) well-defined prediction protocols that allows the task to be experienced as rewarding and effortless.

Several flow studies have shown frontal theta activity related to cognitive control and support for the role of top-down goal-directed processes (De Kock, 2014;

Fairclough et al., 2013; Katahira et al., 2018; Nacke et al., 2010; Wolf et al., 2015; Yun et al., 2017). Top-down processes provide more efficient organization of neural networks typically associated with monitoring and managing cognitive functions that influence whole brain functioning to move into flow (de Sampaio Barros et al., 2018; Huskey, Craighead, et al., 2018; Huskey, Wilcox, et al., 2018). Both neurocognitive models have thus enjoyed strong support not only for cognitive control but also automatization of implicit functions in which nearly all the fMRI flow studies have exhibited striatal activation (Ferrell et al., 2006; Klasen et al., 2012; Ulrich et al., 2016b; Ulrich et al., 2014), along with striatal dopamine in support of the role of implicit control of BG (de Manzano et al., 2013; Gyurkovics et al., 2016). Additionally, these studies also showed a reliance on cerebellar activation, which based on the premise of the inverse model, affords most of the cognitive control to be managed implicitly without a need for explicit interference. Furthermore, as frontal feedback comes online to modulate feedback errors, this may reduce the intensity of flow experience and thereby help resolve some of the THH inconsistencies found in varying reports of hypofrontal activity during flow states.

Furthermore, suppression of explicit functions enabling a transition toward implicit automatized control was reported in several flow studies in support of THH (Bertollo, 2014; Castellar et al., 2019; Fairclough, 2008; Hirao, 2014; Katayose et al., 2006; Yun et al., 2017). It was further shown that support for the freedom of implicit unconscious control requires the inhibition of verbal-analytic functions to remove processing bottlenecks. Many flow studies have revealed reductions in areas responsible for self-monitoring and reflective processing employed during explicit processes which limit the efficiency of the system (Kramer, 2007; Ulrich et al., 2016b; Ulrich et al., 2014; Wolf et al., 2015; Yun et al., 2017). This suppression of analytic processing suggests a further simplification of a complex process to alleviate the need for a division of cognitive resources and thus supporting the implicit function of flow. The inverse model further supports this transition into implicit automatized control in which the cerebellum can take cognitive control away from prefrontal regions thereby offering the person an intuitive experience of something else in control and providing the experience of effortless action.

It can now be seen that flow is also described with features as not just a top-down goal-oriented state associated with the dorsal attention network, but also an altered state of consciousness in which parts of conscious awareness are dissociated in order to provide a more streamlined process of functioning by reducing bottom up irrelevant distractions. Both THH and STF studies have reported an inhibition of the ventral attention network which is associated with stimulus-driven bottom-up processes, in order to prevent reorienting of attention to salient task-irrelevant stimuli which would interfere with task performance (Klasen et al., 2012; Ulrich et al., 2016b; Ulrich et al., 2014). Additionally, Yun et al. (2017) and Castellar et al. (2019) showed distractor suppressions from secondary tasks during flow, regarded as also alleviating from bottom up distractions. Furthermore, the strong results towards striatal D2 dopamine have been considered in the context of impulse control which enables flow to occur due to lowered impulsive behaviour, downregulating focus on task irrelevant stimuli enabling cognitive processing to be more energetically efficient.

To further support this considered dissociation, flow states have been shown to be driven by goal-directed behaviour with high levels of cognitive control based on psychophysiological data in flow studies employing both EEG and ECG (Bian et al., 2016; Gaggioli, Cipresso, Serino, & Riva, 2013; Harris, Vine, & Wilson, 2017; Peifer, 2012). The unique autonomic profile seen in multiple flow studies of parasympathetic activity modulating sympathetic activation support this notion by allowing for goal-directed behaviour that is supported by effective strategies of active coping and successful adaptation. To further modulate what would be a high level of cognitive effort associated with flow, a dissociated experience of effortlessness is facilitated through reduced ACC activity which is reported in multiple neuroimaging studies (Klasen et al., 2012; Ulrich et al., 2016b; Ulrich et al., 2014) making flow a positive coping mechanism to high arousal and attention. Along with ACC reductions, Garrison et al. (2013) showed reductions in DMN led to an experience of effortless action and positive reward during a neurofeedback task for experienced meditators. The role of DMN inhibition in flow states is considered to occur in order to dampen self-awareness which reduces self-evaluated threats allowing for less cognitive resistance as well as affording more rewarding and positive experiences (Ulrich et al., 2016b).

2.2.6 Limitations and future consideration

Neurocognitive research on flow states have begun to provide more consistent results, however there are still major inconsistencies between the research including multiple questionnaires to test flow from different perspectives. While most studies are following the same testing protocol in which participants are probed with questionnaires after engagement in a task, there is the full gamut of tasks testing for flow including car racing games, Tetris, math tasks, and sports for example. Furthermore, a lot of the testing methods will use different measurement protocols ranging from 2 to 64 channel EEGs or a focus on spectroscopy compared to event related potentials or source localization. In general, more agreement is needed to be found during these initial stages of the exploration of the neurocognitive mechanisms of flow states.

The common neurocognitive patterns of activation and suppression that has been described during flow states opens up flow research to the explorative power of transcranial stimulation to further test, probe and elucidate the underlying functioning of flow states. A recent study by Gold and Ciorciari (2019) explored the use of tDCS to support the induction of flow states. TDCS is a noninvasive subthreshold technology that applies small currents across scalp surface electrodes that modulates cortical excitability in the related brain region. Their results showed an increase in reported flow states using a particular montage inhibiting left frontal regions and activating right parietal. Another recent tDCS study by Ulrich et al. (2018) investigated the potential role of the mPFC in flow states, reported in earlier research, by modulating activity levels using tDCS centrally over the prefrontal region. Results showed that tDCS had a greater impact on participants having a low flow experience by a relative inhibition of the right amygdala.

Further understanding can be revealed with more transcranial stimulation studies utilizing higher resolution multimodal imaging techniques along with exploring other stimulation methodologies such as transcranial alternating current stimulation to probe relevant spectral components of flow. TDCS is increasingly used to study motor and non-motor related functions of the cerebellum with a recent review showing effective modulation in both domains but with stronger results in motor functioning (Oldrati & Schutter, 2018). More specifically Yavari et al. (2016) explored cerebellar tDCS (tcDCS) to support ideas of forward, but not inverse, models related to cerebellar regions. Therefore, future studies investigating the interaction of tcDCS on flow states would provide further support into the role cerebellar internal models may provide in the neural mechanics of flow states.

2.2.7 Conclusion

The research body is steadily growing to provide neurocognitive understanding of flow states in which functional commonalities are being further drawn out through both existing neurocognitive models and possibly further built on with the addition of the cerebellar internal models. These greater insights highlighted are now driving new research into probing underlying constructs with new methods such as functional high-resolution imaging and stimulation techniques to both explore and enhance flow states. Specifically, in consideration of the proposed neurocognitive internal model of flow states, research on the use of cerebellar stimulation to facilitate flow states may prove fruitful as an effective induction method. So to would the use of stimulation techniques on the frontoparietal network which has been identified as integral to both STF and THH neurocognitive flow theories. Through the rise of this new wealth of data, it may drive the field to better understand the mechanisms that induce this flow states and ultimately help develop methodologies to help facilitate a movement toward greater levels of performance and optimal functioning across multiple areas in society.

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Chapter 3: Research Questions

Based on the flow introduction and the literature review, two key research questions were formed about the cognitive and neurocognitive underpinnings of flow states. The first research question is informed by the literature on flow in different contexts and the cognitive strategies that facilitate flow.

RQ1: What are the cognitive factors that lead to a higher predisposition in flow states and the differences for recreational and occupational settings?

Based on the current body of academic literature on individuals' preferences using cognitive strategies for accessing flow states and current research for flow states in occupation and recreation tasks, the following hypotheses were generated for the self-report experiment in Part 1:

Publication 3: Peer Reviewed Paper (Submitted)

Abstract: This study explores the key role cognitive and personality strategies play in predicting flow for both professional and recreational settings. Specifically, the extent to which mindfulness mediates the relationship between personality factors (need for cognition and active coping strategies) and experience of flow states is examined across recreational and professional contexts. 107 (56 females and 51 males) participants completed a series of online questionnaires. A multi-group structural equation model was used to test the mediation model across the two contexts. Results revealed that mindfulness significantly mediated the relationship in professional settings

and overall, but not in recreational settings. The results of this study further expand on how mindfulness is relevant to the experience of flow and considers the implications of context.

Aim: Determine a model of the cognitive strategies for people who find flow in occupational and recreational settings.

Hypothesis 1. When explaining flow predisposition, mindfulness moderates active coping strategies and need for cognition.

Hypothesis 2. There is a difference in the reliance of cognitive strategies such as mindfulness and coping when explaining flow predispositions for people finding flow in occupational and recreational settings.

Gold, J., Ciorciari, J. and Critchley, C.R. (2020) The moderating role of mindfulness in predicting flow traits during recreation and work. Personality and Individual Differences. (Submitted July 2020)

In Part 2 of the thesis, the second research question arose from the differing and disparate literature on the neurocognition of flow states and therefore sought to explore the functional neural networks that facilitate entrance into flow states.

RQ2: How can transcranial direct current stimulation help determine the neurocognitive functions of flow and improve induction of flow states for recreational and occupational participants?

The following hypotheses presented took into consideration the findings on the different cognitive approaches for recreation and occupation flow tasks from part one in order to more effectively explore the nuance that exists in differing levels of expertise when considering neurocognitive networks of flow states. These hypotheses thus, explored the individual neurocognitive differences novice and expert performers experienced from the application of tDCS, first in a domain general experiment and then specifically for flow states:

Publication 4: Peer Reviewed Paper (Submitted)

Abstract: Effective anticipation skills in sporting cognition have been shown to facilitate expertise in sports. Transcranial direct current stimulation (tDCS) has shown to improve motor and cognitive functioning. Therefore, this study aimed to determine the assistive effects of tDCS on the action observer network (AON) in both novice and expert gamers during an occlusion task as well as the related EEG spectral power response. 23 novice and 23 expert video gamers received either sham or active tDCS with a right parietal anode and left frontal cathode. Only experts demonstrated a significant improvement in predicting ball direction for the overall and early occlusions after tDCS. Spectral power results revealed significant changes in theta, high-gamma and delta frequencies. The findings indicate tDCS was able to modulate anticipatory

behavior and cortical activity in experts compared to novice participants, suggesting a facilitatory role for tDCS to improve anticipatory effects and assist as a neurocognitive training technique.

Aim: Determine the assistive effects of tDCS on the action observer network in both recreational and occupational gamers during a soccer goalie occlusion task.

Hypothesis 1. tDCS would improve accuracy of performance in the temporal occlusion task.

Hypothesis 2. Higher frontal theta synchronisation (increase) after tDCS for participants performing with higher accuracy during the temporal occlusion task.

Gold, J. and Ciorciari, J. (2020) Impacts of transcranial stimulation on sports occlusion task and its frequency power profile, Journal of Sport & Exercise Psychology, (Submitted April 2020)

Publication 5: Peer Reviewed Paper

Abstract: *Background:* Flow states are considered a positive, subjective experience during an optimal balance between skills and task demands. Previously, experimentally induced flow experiences have relied solely on adaptive tasks. *Objective:* To investigate whether cathodal transcranial direct current stimulation (tDCS) over the left dorsolateral prefrontal cortex (DLPFC) area and anodal tDCS over the right

parietal cortex area during video game play will promote an increased experience of flow states.

Methods: Two studies had participants play Tetris or first-person shooter (FPS) video games while receiving either real tDCS or sham stimulation. Tetris recruited 21 untrained players who infrequently played video games while the 11 FPS participants played FPS frequently. Flow experience was assessed before and after stimulation.

Results: Compared to sham stimulation, real stimulation increased flow experience for both untrained Tetris and trained FPS players. Improved performance effects were only seen with untrained groups.

Conclusion: Cathodal and anodal tDCS over the left DLPFC and right parietal areas, respectively may encourage flow experiences in complex real-life motor tasks that occur during sports, games, and everyday life.

Aim: tDCS during video game play will promote an increased experience of flow state intensity for both occupational and recreational users of video games.

Hypothesis 1: tDCS along the fronto-parietal network will result in a higher scores of flow states.

Hypothesis 2: Only recreational users will receive a performative benefit from tDCS.

Gold, J. and Ciorciari, J. (2019) A Transcranial Stimulation Intervention to Support Flow State Induction. Front. Hum. Neurosci. 13:274. doi: 10.3389/fnhum.2019.00274

Publication 6: Future Publication

An additional paper is currently in the process of completion that focusses on electroencephalography (EEG) and magnetoencephalography (MEG) measurements to investigate the neurocognitive correlates of flow for people at different levels of expertise. Additionally, this study will be coupled with tDCS to provide support in helping to understand how neurocognitive activity changes in flow states after tDCS induction. This paper was not included in the thesis at the recommendation of Swinburne University's review panel due to concerns over time constraints and the acknowledgment that the Thesis already satisfied the requirements of the PhD candidature. This paper is currently being prepared and intended to be submitted for publication in the near future.

Aim: Investigate neurocognitive correlates of flow states identified in the this thesis (Publication 2) across different levels of expertise using both EEG and MEG. Furthermore, the change of neural correlates of flow states will be investigated with tDCS.

Chapter 4: Research Methodology

4.1 Introduction

This thesis's experimental design ran two studies with similar testing paradigms across two context based populations that produced two papers as well as a general online self-report component that produced a single paper, therefore this methodology chapter will summarize the research design and methodology for the three publications of the three experiments by denoting whether it is for Publication 3 (P3), Publication 4 (P4) or Publication 4 (P5) . The methodology is further broken up to explain the research design, methodology and analysis for the three papers included in this chapter. Additional measures were included in the experiment but were not used and can be found in Appendix 11

Publications included in this chapter:

Publication 3: Peer Reviewed Paper (Submitted)

Gold, J., Ciorciari, J. and Critchley, C.R. (2020) The moderating role of mindfulness in predicting flow traits during recreation and work. Personality and Individual Differences. (Submitted July 2020)

Publication 4: Peer Reviewed Paper (Submitted)

Gold, J. and Ciorciari, J. (2020) Impacts of transcranial stimulation on sports occlusion task and its frequency power profile, Journal of Sport & Exercise Psychology, (Submitted April 2020)

Publication 5: Peer Reviewed Paper (Published)

Gold, J. and Ciorciari, J. (2019) A Transcranial Stimulation Intervention to Support Flow State Induction. Front. Hum. Neurosci. 13:274. Doi: 10.3389/fnhum.2019.00274

4.2 Methodology and research design

The research design was developed for this project as two similar experimental designs across two contextual populations with recreational flow task participants tested in MEG and occupational flow task participants tested in the EEG and each experiment comprised of two studies. The first study was a soccer goalie temporal occlusion task (P4) and the second was a video game flow task (P5). These experiments were also modulated with an experimental component utilizing transcranial direct current stimulation (tDCS). Additionally, publication 3 was conducted as an online battery of questionnaires. Individual descriptions of the research design, methodology, methods are also provided in the publications included in this thesis.

4.3 Participants

Online (P3): A battery of questionnaires was administered online to 107 people, which included 56 females and 51 males with an age range of 4.6% for 18-24, 58.7% for 25-34, 28.4% for 35-44, 8.2% for 45+ to determine how different psychological variables might impact flow disposition. Based on participants answers to what task they experienced flow states in, 53 indicated experiencing flow during occupational tasks while 54 during recreational tasks. This was run as an online survey with 107 participants.

Recreational (P4 & P5): Twenty-three right-handed participants were asked to play an adapted version of TETRIS® (P5) and a soccer goalie occlusion task (P4) of which eleven were male (M = 31.8 years, SD = 3.61) and twelve were female (M = 30.18 years, SD = 6.14). Participants were infrequent gamers who on average played videogames once a month. Individuals were recruited through forums and by word of mouth at the Swinburne University of Technology campuses (See Appendix 9). TETRIS was used for the recreational group as all participants were familiar with how to play it. Participants were randomly assigned between active and sham transcranial direct current stimulation (tDCS) conditions. It was a requirement for participation that subjects had some aptitude of the game Tetris in which 100% of participants positively answered.

Occupational (P4 & P5): Twelve right-handed males (M = 29 years, SD = 7.15) played a 1st person shooter videogame (FPS) (P5) and a soccer goalie occlusion task (P4) across two sessions within a week using randomized active and sham tDCS conditions. Participants had a strong aptitude of the first-person shooter games and indicated frequent game use several times a week and participated in competitive games. Subjects were primarily recruited by the researchers through word of mouth or gaming forums (See Appendix 9). Informed consent was given by all subjects before participating in the study.

4.4 Experimental tasks

Flow studies typically use two styles of flow designs. The first is based on a flow inducing task that would enable a person to enter into a flow state and then the participant would answer a retrospective inter-task questionnaire about the level of flow the participant was in. This method has evolved out of the original ESM methodologies originally developed and implemented by Csikszentmihalyi (1975). This design was implemented for occupational video gamers that played frequently at an expert level and were offered a more familiar route into flow states through typical game play. This method however would less likely result in flow states for recreational video gamers that played at a novice level. Therefore, a second flow design was developed out of Csikszentmihalyi's (1990) challenges/ skill flow cycle that utilizes the key stages of boredom, anxiety and flow by implementing dynamically adjusted levels in an adapted version of TETRIS® (Tetris Holding) to help facilitate flow for infrequent novice video game players.

Publication 5

<u>Recreational:</u> The experimental task was based on the design in Harmat et al. (2015) which consisted of a modified TETRIS game. The game's code is sourced from

http://www.percederberg.net using the GNU General Public License and was used on a desktop gaming PC. The code was adapted in Java code to be able to manipulate the trial conditions. The code can be found in Appendix 6.

TETRIS uses geometrical objects called tetrominoes, made up of four squares, conjoined in different patterns (Golomb, 1994) that fall vertically from the top to the bottom of the screen, a piece at a time. As the piece descends, a player can drop a falling piece, move it left and right or rotate it, with arrow keys. The aim is to align the pieces to create whole horizontal rows that disappear to gain points. In this studies version of TETRIS, the falling pieces speed varies over 13 different levels, which relates to 13 different difficulty levels. When five or more complete rows are created then the fall rate speed increases by one level. Additionally, there are four buttons to control the movement of the tetromino pieces. Left and right buttons toggle the pieces to the left and right. Up button spins the shape 90 degrees, and down button drops the piece to the bottom of the screen. To make sure psychological states are varied during the experiment, subjects played in all three difficulty trials (Slow/ Boredom, Fast/ Anxiety and Adaptive/ Flow). Each participant would play all three conditions in the experiment and the speed would increase if 5 or more lines were completed regardless of which condition was being presented. Additionally, there was a practice trial before testing began in which the participant got to familiarize themselves with the game playing the adaptive flow level for 15 minutes.

In the Boredom condition, the tetromino piece fall rate was set at level two to start the trial and the drop-down button was disabled, forcing the person to wait for the piece to reach the bottom of the screen, which made the game too easy for all participants as reported by them. in the Anxiety condition, the fall rate was set to level eight which is four steps above the starting rate of the Flow level and was described by all participants as high difficulty. In the Anxiety and Flow trials, a participant can also utilize the down arrow to instantaneously drop a falling piece, which creates a greater control and skill/challenge modifier. In the Flow condition, the speed started at level 4 and was adjust throughout the trial to adapt to the subject's performance that is measured based on an algorithm written into the code (Keller & Bless, 2008). If the participant succeeds in forming five or more complete rows with 30 pieces, the difficulty increases by one speed level. Yet, If only three or fewer complete rows are formed, the difficulty increases by one speed level.

Occupational: The experimental task consisted of the participant choosing between two FPS games: "Counter Strike: Global Offensive" (Valve) or "Battlefield 4" (EA) video gamers. Both games had the same settings of competing in a live online multiplayer virtual room of 20+ competitors, scored on most kills wins and played only in a single map environment. Due to different map, weapon and control settings, two games were used to allow players to participate in the FPS game they felt most proficient in to give them the best chance to enter into flow.

Publication 4

Occlusion Task: The task was run through the PsychoPy software and implemented on a desktop gaming PC. The code was adapted in Python code to be able to manipulate the trial conditions. The code can be found in Appendix 6.

A pre-and post-test group design was implemented to test before and after the tDCS intervention using soccer kicking anticipation tests as a goalie video simulation based on occlusion tests developed by Müller, Abernethy, and Farrow (2006). A soccer video simulation was used to investigate the participant's capacity for advanced information and determine if tDCS intervention could improve functionality by measuring score accuracy from the predicted directions of the ball after the point of occlusion. Each participant watched footage of different people kick a soccer ball toward them until temporal occlusion occurred and then indicate using a choice of three different directional arrows on the keyboard which way the ball would be kicked (see Figure 4.1).

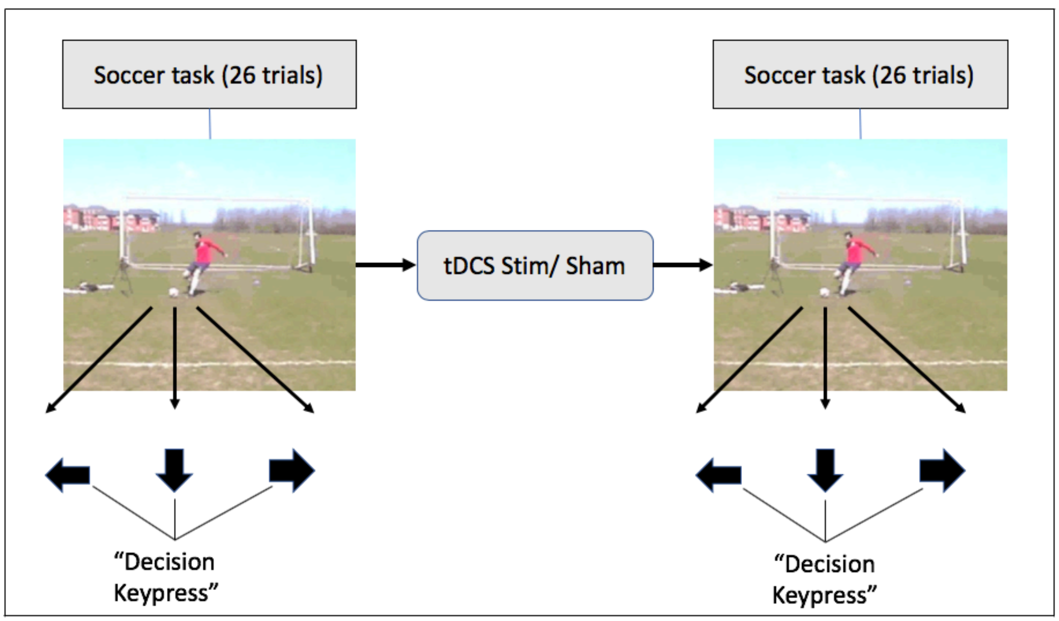

Figure 4.1: Publication 4 - occlusion experiment design

The soccer simulation included 26 randomized video trials consisting of three kick types x two temporal occlusion conditions at two intervals (before and after stimulation or sham conditions). Participants were asked to prepare for each trial by staring at the fixation cross and then press any button to signify their readiness. Light markers were used to time lock video with participants' decision time points with EEG (See Figure 4.2).

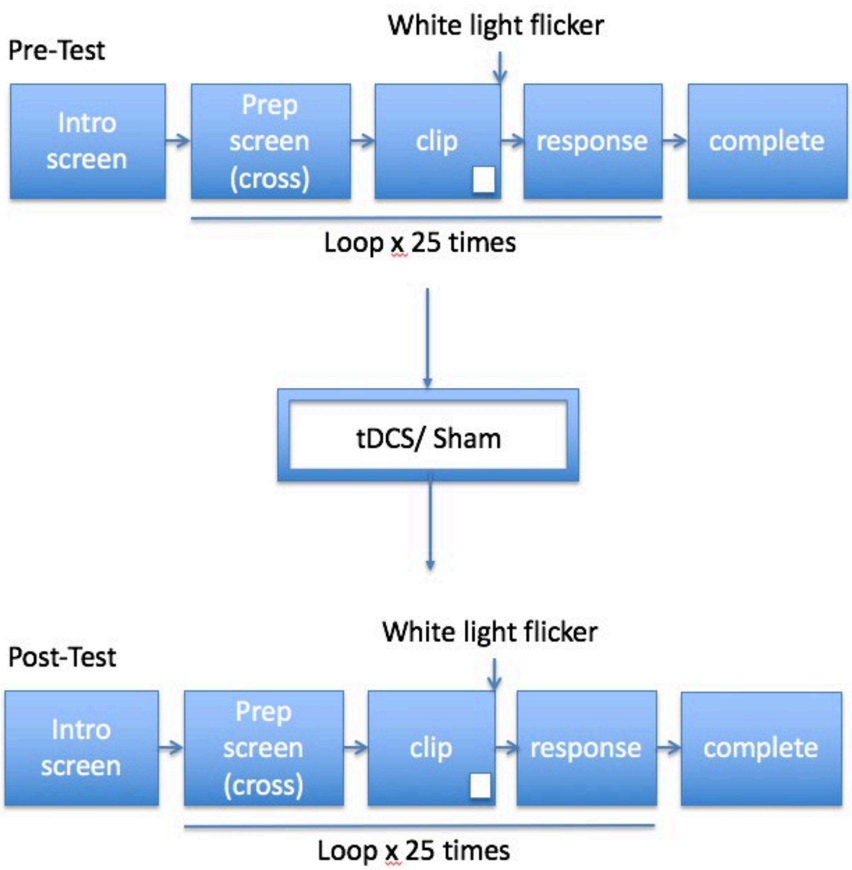

Figure 4.2: Publication 4 - occlusion experimental protocol

4.5 Neurostimulation

TDCS stimulation was applied using a NeuroConn DC-Stimulator (NeuroConn GmbH) machine with a montage of left prefrontal cathode and right parietal anode. tDCS was administered via two 5cm × 5cm rubber electrodes covered with saline-soaked sponges. The stimulation site was determined by means of the 10/20 system. The anode was positioned over F3, according to the 10-20 EEG system. The cathode was placed over P6. Whilst tDCS excitability changes have been shown to last up to 60 min (Nitsche & Paulus, 2001), results have shown performance effects dwindle after 30 min of stimulation (Iyer et al., 2005). Therefore, stimulation condition was set for 20 minutes (including 10 seconds ramp-up and 10 seconds ramp-down time) at 2mA, while sham condition also lasted 20 minutes but was set for 30 secs of stimulation at 1mA. Participants are shown typically unable to determine whether receiving real or sham stimulation (Gandiga, Hummel, & Cohen, 2006).

4.6 Self-Measure

For all experiments including P3, P4 and P5, participants were asked to complete the 34-item NFC, the 39-item Five Facet Mindfulness Questionnaire, the 28-item Brief COPE Scale, the 36-item Dispositional Flow Scale and a short questionnaire designed to inform the researchers of participants' basic details, and any health concerns prior to the study. These can all be found in Appendix 3 for P4 and P5 and Appendix 4 for P3.

The Five Facet Mindfulness Questionnaire (Ruth A. Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006) was measured by asking participants to indicate their frequency of participating in different aspects of mindful behaviours using a five-point Likert scale ranging from 1 – "never or very rarely true" to 5 – "very often or always true".

The Need for Cognition (NFC) was assessed using 34-item scale (John T. Cacioppo & Petty, 1982). Participants were asked to indicate on a 5-point Likert scale ranging from 1 – “extremely uncharacteristic of me” to 5 – “extremely characteristic of me”.

The Brief COPE (Carver, 1997) was assessed using 28-item scale and measures ways people cope with stress in their lives. Participants were asked to indicate on a 4-point Likert scale ranging from 1 – “I haven’t been doing this at all” to 4 – “I’ve been doing this a lot”.

The Flow Disposition Scale (DFS-2) (Jackson and Eklund, 2004) which is composed of 36 items representing the nine dimensions of flow: challenge–skill balance, action/awareness merging, clear goals, unambiguous feedback, intense concentration, control over the task at hand, loss of self-consciousness, transformation of time, and autotelic experience. The DFS-2 was measured by asking participants to indicate their frequency of thoughts and feelings associated with flow while participating in their typical flow activity. Each item is answered in a 5-point Likert-type scale varying between 1-Completely disagree and 5-Completely agree.

Publication 5

Additionally, participants were asked to complete the Intergame Flow questionnaire after every game trial whether it be a gaming round in the FPS for the occupational group or after a trial for each TETRIS condition in the recreational group. The Intergame Flow questionnaire measures flow state using an enlarged version of the Flow State Scale (FSS-2) (Jackson and Eklund, 2004). The FSS-2, has been implemented across different studies for varied samples to have valid psychometric properties (Kawabata, Mallett, & Jackson, 2008). Questions are presented instead as statements of subjective experiences for the previous task, such as “I had total concentration”, with a response either in agreement or disagreement. Responses are on a continuous scale with dashes scoring from 1 (strongly disagree) to 10 (strongly agree). Two additional core questions were added to the FSS-2: “Everything Clicked” and “I was ‘in the zone’.”

4.7 Experimental procedure

Publication 5

Recreational. Experimental procedures are explained to subjects upon entry to the laboratory. They are first then seated and fitted with positional sensors, then for the experiment the participant is moved into the MEG sitting upright in front of the projector.

Participants would begin with a 3-minute baseline condition with eyes closed, relaxed breathing and hands resting on legs. They then were asked to play a 15-minute warm up of the adaptive condition of TETRIS prior to testing to determine at what testing level they should start. The participants would then be informed about a change in the gaming condition and they would complete three trials of the slow, fast and then adaptive TETRIS games for approximately three minutes. The researcher would then request they complete the Inter-Game Flow Questionnaire after each trial. Afterwards participants would randomly receive the stimulation or sham condition for 20 minutes, whilst playing the adaptive condition, again completing the Inter-Game Flow Questionnaires. Participants would again complete the 3-minute baseline condition after stimulation or sham. Then participants would play two more trials each of the adaptive and fast conditions with the Inter-Game Flow Questionnaire (See Figure 4.3).

<u>Occupational</u>: On arrival at the laboratory, participants were informed about the experimental procedure and given a series of questionnaires. The participant then had a 64-channel EEG cap placed on their head. Participants were seated in a chair, adjusted according to their height, located in a sound-attenuated RF shielded room. Participants would begin with a 3-minute baseline condition with eyes closed, relaxed breathing and hands resting on legs. Participants then chose their game and were then randomly assigned a stimulation or sham condition. Players then entered an online FPS room with 16 or more online players. The games' objective is to stop the other team therefore game scores were based on number of kills. Participants played a warmup round for about 20 mins before beginning testing. During testing, when a participant had played beyond 3 minutes, if they had completed two kills in a row without dying, they would be notified with a flashing light controlled by the researcher to fill out the Inter-Game Flow Questionnaire. The participant would press a button to acknowledge the light flash before answering the questionnaire.

After 8 rounds, participants would stop and randomly receive the stimulation or sham condition for 20 minutes. Participants would then do another 3-minute baseline and afterward begin another testing session with the Inter-Game Flow Questionnaire. Participants would then return a week later and participate again with same experimental protocol but receiving the opposite stimulation condition (See Figure 4.3). The complete experimental checklist and room layout can be seen in Appendix 7 along with a screenshot of the FPS game map.

Publication 4

EEG occlusion: On arrival at the laboratory, participants were informed about the experimental procedure and given a series of questionnaires. The participant then had a 64-channel EEG cap placed on their head. Participants were seated in a chair, adjusted according to their height, located in a sound-attenuated RF shielded room. Participants would begin with a 3-minute baseline condition with eyes closed, relaxed breathing and hands resting on legs. Participants would begin with a 3-minute baseline condition with eyes closed, relaxed breathing and hands resting on legs. Afterward they were instructed to complete the soccer occlusion task. Afterward participants would randomly receive the stimulation or sham condition for 20 minutes. Participants would again complete the 3-minute baseline condition and soccer occlusion task (See Figure 4.4).

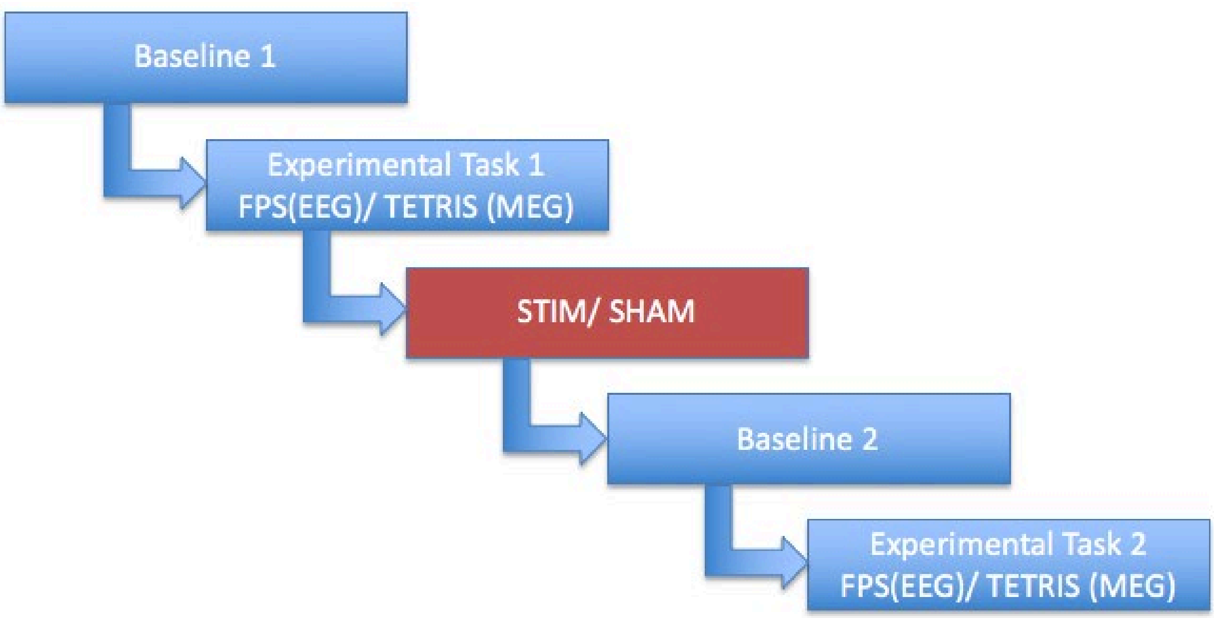

Figure 4.3: Publication 5 - Procedural pipeline for MEG/ tDCS and EEG/ tDCS experiments

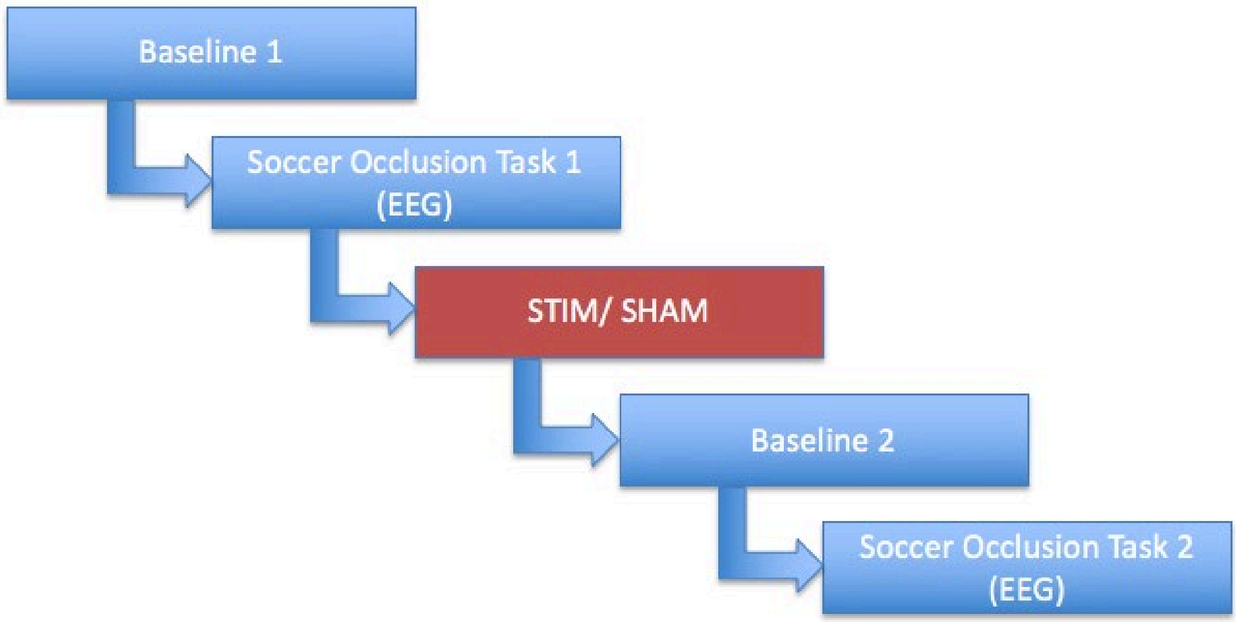

Figure 4.4: Publication 4 - Procedural pipeline for soccer occlusion EEG/ tDCS experiment

4.8 Physiological measures and analysis

Physiological recordings were taken throughout the three experimental TETRIS trials for MEG and throughout the FPS for the EEG (see Experimental procedure), using the Elekta NeuroMag MEG and Neuroscan systems, respectively. A sampling rate of 1000 Hz was used for all channels. The recommended standard filter settings were used for all measurements (See Figure 4.5 and 4.6 for analysis breakdown). The following measurements were performed:

Recreational (P5). MEG was recorded with a Neuromag Elekta MEG with additional ECG leads. Recordings were first MaxFiltered and then the recorded data was imported first to MNE analysis software where an independent component analysis (ICA) was performed and a band pass filter from 1Hz – 100Hz. The data was then imported across to brainstorm, which notch filtered at 50Hz, decimated to 250Hz and epoched the data into 1.5sec intervals. The code for the Maxfiltering and MEG preprocessing pipeline was written in Python and can be found in Appendix 6.

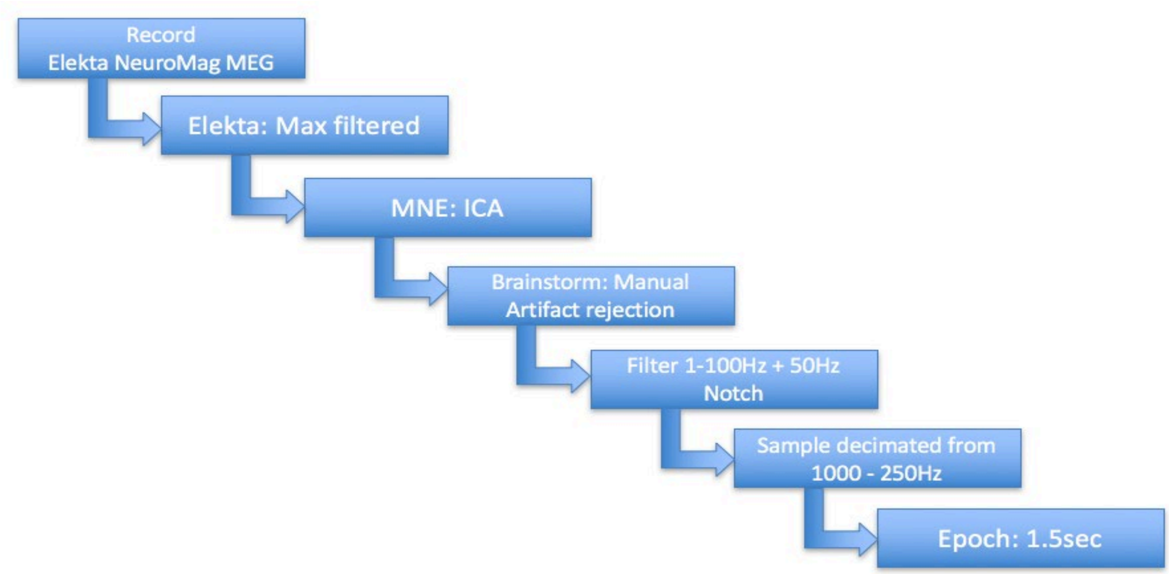

Figure 4.5: MEG Analysis pipeline

Occlusion/ Occupational (P4 + P5): To measure the soccer occlusion task and flow states during the FPS video game, a Neuroscan 64 channel EEG was used. All scalp electrode impedances were kept below 5 kΩ and were referenced via both mastoid bones and grounded via the cap. Electrode recordings were fed to a set of amplifiers (Nuamps) with a 500 gain, a band-pass of .01- 100 Hz and a sample rate of 1000 Hz. Baseline EEG data was also assessed in an initial phase where participants were instructed to rest for a moment (eyes open, eyes closed) before they started with the experimental procedure. The recorded data was imported to Neuroscan Edit Suite where careful examination of the recording resulted in manual removal of artifacts, replacing channels with surrounding electrodes, decimating to a sample rate of 250Hz and an average re-referencing across all electrodes. Then the data was moved across to brainstorm where an ICA was performed and then dc and linear trend correction, as well as a 50Hz notch and a band pass filter from 1Hz – 100Hz. The data was then epoched into 1.5sec intervals. Each condition was averaged over the participant and then those averages were then averaged as a grand average for the condition. Each condition was assessed for topographical amplitude, and spectral frequency patterns.

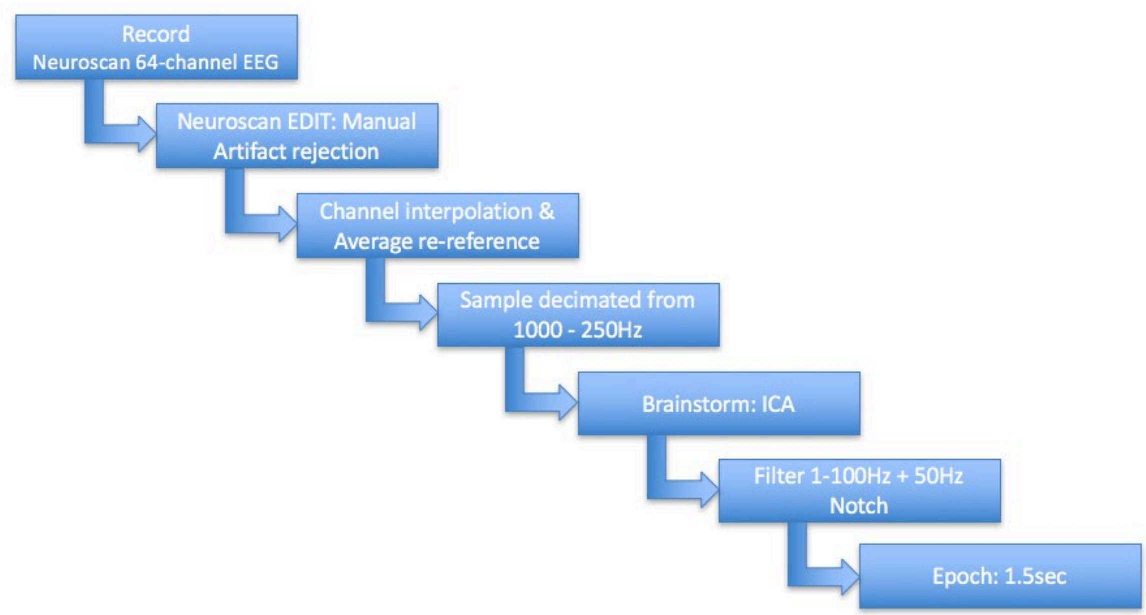

Figure 4.6: EEG Analysis pipeline

4.9 Statistical design and analysis

Publication 5

Recreational: A mixed ANOVA was used to determine a significant main effect of the dependent variable, perceived state of flow score, during the events associated with each of the trials and games; e.g., this was compared to lines completed in TETRIS during different conditions. Similarly, a mixed ANOVA was used to determine a significant main interaction effect for tDCS stimulation with each of the trials and games.

Occupational: A repeated-measures analysis of variance (ANOVA) was used to assess the significant main effect of the dependent variable, perceived state of flow score, during the FPS video game before and after the two trials (tDCS and sham).

Publication 4

Occlusion: Evoked response spectral power (ERSP) analyses were run to determine changes in frequency power as measured by the time-frequency decomposition using the complex Hilbert transform (central frequency: 1 Hz, time resolution at full width at half maximum: 3secs). Statistical comparisons were made using Brainstorm statistical tools on the frequency mean differences between novice and expert gamers who received tDCS using independent 2-tailed parametric t-test for low frequency activity (delta 2-4 Hz & theta 5-7 Hz) and high frequency (gamma 30-59 Hz). T-test data cannot be exported from Brainstorm and hence analysis was not run on sham participants due to the limitation of Brainstorms statistical versatility and the fact that a difference was already ascertained through the behavioral data. Average spectral power at scalp electrode sites was obtained for both novice and expert active stimulation condition. Statistically significant differences ($p < .05$) in power spectra were plotted across the topography for the two expertise stimulation conditions along with temporal t-scores across the period both pre- and post-occlusion event.

4.10 Ethics Clearance

Ethics approved by the University Human Research Ethics Committee, SUHREC Project No: SHR Project 2014/310 (Appendix 5).

Chapter 5: Part 1- The Psychological Role of Cognitive Strategies in Explaining Flow Traits.

5.1 Part 1 Introduction

Part 1 addresses the first research question in chapter 3 of this thesis in the following paper by investigating the role of cognitive strategies that explain a higher predisposition of flow traits across flow tasks achieved in recreational and occupational settings.

5.2 Publication 3: Rationale

This paper presents the results for part 1 of the thesis which determines the impact mindfulness has as a moderating cognitive strategy in explaining a predisposition towards higher flow traits and the influence of active coping and need for cognition variables. This paper then addresses the explanatory power of this model across occupational and recreational flow tasks. It uses an online questionnaire study which measure changes in individuals flow traits and indicates cognitive strategies people tend to be more likely to utilize during situations that require higher cognitive workloads.

While this paper has not been accepted for publication yet, it has been peer reviewed and provided with helpful comments. The reviewers' comments were addressed in the following paper which can be found in Appendix 2.

Gold, J., Ciorciari, J. and Critchley, C.R. (2020) The moderating role of mindfulness in predicting flow traits during recreation and work. Personality and Individual Differences. (Submitted July 2020)

5.3 Publication 3: The moderating role of mindfulness in predicting flow traits during recreation and work

5.3.1 Abstract

This study explores the key role cognitive and personality strategies play in predicting flow for both professional and recreational settings. Specifically, the extent to which mindfulness mediates the relationship between personality factors (need for cognition and active coping strategies) and experience of flow states is examined across recreational and professional contexts. 107 (56 females and 51 males) participants completed a series of online questionnaires. A multi-group structural equation model was used to test the mediation model across the two contexts. Results revealed that mindfulness significantly mediated the relationship in professional settings and overall, but not in recreational settings. The results of this study further expand on how mindfulness is relevant to the experience of flow and considers the implications of context.

Keywords: flow, need for cognition, coping, mindfulness, personality, recreation, occupation

5.3.2 Introduction

Flow has been described as smooth and accurate performance with an acute absorption in the task to the point of time dissociation and dissociative tendencies (Csikszentmihalyi & Csikszentmihalyi, 1988; Nakamura & Csikszentmihalyi, 2002; Rheinberg, Vollmeyer, & Engeser, 2003). Whilst flow is considered a ubiquitous state, due to its elusiveness in everyday experiences, Csikszentmihalyi (1990) suggested that there is a dispositional consideration for flow states. How often a person tends to experience flow is conceptualized as dispositional flow (Jackson, Thomas, Marsh, & Smethurst, 2001). Flow is further described as a state of optimal performance in which the enjoyment of a task is due to a discovery within the interaction.

In exploring the key dispositions that impact flow, empirical studies have shown flow experience is highly correlated with complex cognitive activities (Landhäußer & Keller, 2012). Ullén et al. (2012) showed however, that intelligence is less important than personality factors for flow disposition. For instance, individuals with autotelic personalities, which indicates high levels of intrinsic motivation, have also been shown more likely to experience flow than others (Keller & Blomann, 2008; Tse, Nakamura, & Csikszentmihalyi, 2020). Autotelic personality has even shown to have specific neurobiological (de Manzano et al., 2013; Gyurkovics et al., 2016) and genetic contributions (Mosing et al., 2012). Therefore, in determining personality factors that have been related to flow and address intrinsically motivated complex cognitive processing, the study chose to focus on mindfulness, need for cognition (NFC) and coping as three prominent cognitive factors in the literature that may help explain entrance into flow states.

NFC helps explain individual differences in the intrinsic enjoyment of effortful processing of cognitive tasks (Cacioppo & Petty, 1982), in which varying levels of NFC results in different cognitive habits and behavioral patterns. Participants presenting high on the NFC scale show an enjoyment of effortful thinking, such as solving puzzles and abstract thinking. However those who score low in NFC tend to avoid effortful thinking (Petty, Cacioppo, & Schumann, 1983). Furthermore, high NFC people have been shown to have more frequent and positive experiences with external stimuli such as tasks that require deliberative processing and also result in more effective problem solving outcomes (Cacioppo, Petty, Feinstein, & Jarvis, 1996). In flow studies, NFC has presented positive correlations with flow related elements such as intrinsic motivation, focused attention and perceived control which are considered key components to flow dispositions (Li & Browne, 2006; Srivastava, Shukla, & Sharma, 2010). Furthermore, both flow and NFC have shown similar personality associations with positive associations for conscientiousness and an inverse relationship with neuroticism (Ullén et al., 2012). Li and Browne (2004) believed that due to the higher engagement in cognitive activities, high NFC people have a better ability to prevent surrounding noises from interfering with the task.

Csikszentmihalyi (1990) suggested that flow can be described from the perspective of stress coping strategies, in which the way a person experiences challenge has greater relevance than the actual challenge experienced (Jackson & Eklund, 2004). Cortisol is directly related to regulating the stress response. Whilst it is traditionally known as the “stress hormone” (Ulrich-Lai & Herman, 2009), studies have shown that cortisol also helps with the coping process by influencing stress responses

(Putman & Roelofs, 2011). Cortisol has been shown to prepare for additional energy demands (Benedict et al., 2009) by enhancing blood glucose effectiveness, thus providing an additional source of energy to enable a readiness for action (Sapolsky, Romero, & Munck, 2000). Lovallo and Thomas (2000) use Lazarus and Folkman's (1984) transactional stress model to explain a two-step appraisal approach in which an individual first assesses the threat and then their ability to cope with it. Peifer (2012) also associates this model in her flow research with Baumann and Scheffer (2010) “seeing difficulty; mastering difficulty” approach which suggests that the stressor results in an increased cortisol release that then provides additional resources for mastering the task. This has been supported by studies showing cortisol release improving cognitive function and attention (Lundberg, 2005; McEwan & Seeman, 1999). Cortisol has also been positively correlated in flow studies testing video games (Keller, Bless, Blomann, & Kleinböhl, 2011). However, Peifer (2012) showed when cortisol effects are enduring it can also have a negative impact on performance such as cognitive impairment. Therefore, it is believed that there is a level of stress coping management necessary to allow for a balance necessary for an induction of flow states.

Csikszentmihalyi (1990) explained that “those who know how to transform a hopeless situation into a new flow activity that can be controlled will be able to enjoy themselves and emerge stronger from the ordeal” (p.203). Active coping emphasizes problem solving, communications, and control and refers to the behavioral strategies used to modify the stressor itself (problem-focused coping) or psychological responses of how a person thinks about it (emotion focused coping). Active coping has been shown to result in individuals successfully coping with stressful situations by learning to reframe stress and with an orientation to challenge (Kumpfer, 1999; Malik, 2010). Asakawa (2010) showed in a study with Japanese college students how active coping strategies positively impacted the occurrence of flow experience and that the students with greater tendencies to experience flow had higher self-esteem, lower anxiety, and had a greater inclination to utilize active coping strategies than passive coping strategies.

In the book Flow: The Psychology of Optimal Experience (1990), psychologist Mihaly Csikszentmihalyi reports that heightened attention is a fundamental aspect of the experience of flow. Meditation is often regarded as a self-regulation strategy with a focus on modifying or training attention (Walsh & Shapiro, 2006). Recent literature reviews demonstrate that meditation practice is an effective intervention for improving emotional well-being (Greeson, 2009) as well as improved cognition (Dillbeck, Assimakis, Raimondi, Orme-Johnson, & Rowe, 1986) and enhanced prolonged attention (Lutz, Slagter, Dunne, & Davidson, 2008; Tang et al., 2007). This has led researchers to explore more closely what the effects of modifying attention may have on experiences of flow. To this end, Clark (2002) investigated how the modification of attention through mindfulness practices would affect graduate students in education, in which results showed that three of the six participants reported an increase in flow based on their practice. Other studies have also found an increase in flow experiences using mindfulness-based practices (Kaufman, Glass, & Arnkoff, 2009; Thienot, Bernier, & Fournier, 2009; Thompson, Kaufman, Petrillo, Glass, & Arnkoff, 2011). In particular, several elements of flow, such as immersion in the task, loss of self-consciousness, are considered correlated with the mindfulness characteristics of awareness (Kaufman, Glass, & Pineau, 2018). Acting with awareness in the Five Facet Mindfulness Questionnaire (FFMQ) describes the focus of attention to one's activities in the moment, rather than behaving mechanically while attention is focused elsewhere. An important aspect of acting with awareness is that it is the primary factor to focus on attention of the environment while the remainder of the FFMQ components focus on the relationship to a person's thoughts. A study by Cathcart, McGregor, and Groundwater (2014) found results of elite athletes experiencing the highest frequency of flow had the highest disposition to mindfulness of the ability to act with awareness. Love, Kannis-Dymand, and Lovell (2019) also found an association primarily with a strong positive association between acting with awareness and flow states post competition for triathletes showing the importance of attention and ability to remain focused on the task as a predisposition for entrance into flow.

While flow studies have shown that it can occur in many different contexts, i.e. work or leisure activities, it is important that the task is creative in its domain and promotes satisfaction in the use of personal skills. In turn, it facilitates the search for more challenging opportunities for action and thus cultivates a lifelong interest (Csikszentmihalyi, 1979). For example, in a study by Csikszentmihalyi and LeFevre (1989) flow experience was experienced more frequently in work than leisure activities, yet managers spent the most time in flow state at work than both clerical or blue-collar workers. Furthermore, managers and blue-collar workers recorded low creativity in leisure nonflow tasks, while clerical workers recorded low creativity for work nonflow tasks. Csikszentmihalyi (1990) further suggested the experience of flow depends both on environmental as well as physiological factors that rely on internal (e.g., personality disposition) and external (e.g., contextual and social) characteristics.

Implicit and explicit motivations between leisure and work tasks have been related to the quality of experience a person has within the task. For instance, Love et al. (2019) reported that athletes whose motivation were competitive reported higher flow levels compared to those who were only competing recreationally. Those with competitive motivations were believed to have more effective metacognitions to manage the stressors of the event such as beliefs and worry while those whose motivations were based on external goals such as social capital recorded lower scores in mindfulness (acting with awareness). Therefore, it is critical to understand the cognitive strategies that a person is predisposed to in order to understand how they can best manage their motivations and expectations in order to reach the highest quality of flow experience.

This study’s main objective was to explore the role of key cognitive strategies people are predisposed to utilizing, in order to better determine the role personality plays in facilitating flow states in general. In particular, we wanted to investigate the relationship between NFC, mindfulness – acting with awareness and active coping strategies have with the experience of flow states. The current research therefore proposes that the relationship between NFC and problem focused coping and flow will be explained by mindfulness. In other words, it is NFC and coping which help explain mindfulness which in turn helps explain a general tendency to experience flow states (see Figure 1).

Additionally, this study addressed the role of cognitive strategies people are predisposed to use as dimensions of personality to consider their impact as a facilitator for flow states for people who predominantly experience flow in work tasks compared to recreational tasks. Given the additional external stressors associated with a work context, we expect mindfulness to be of greater importance in predicting flow in work compared to recreational environments.

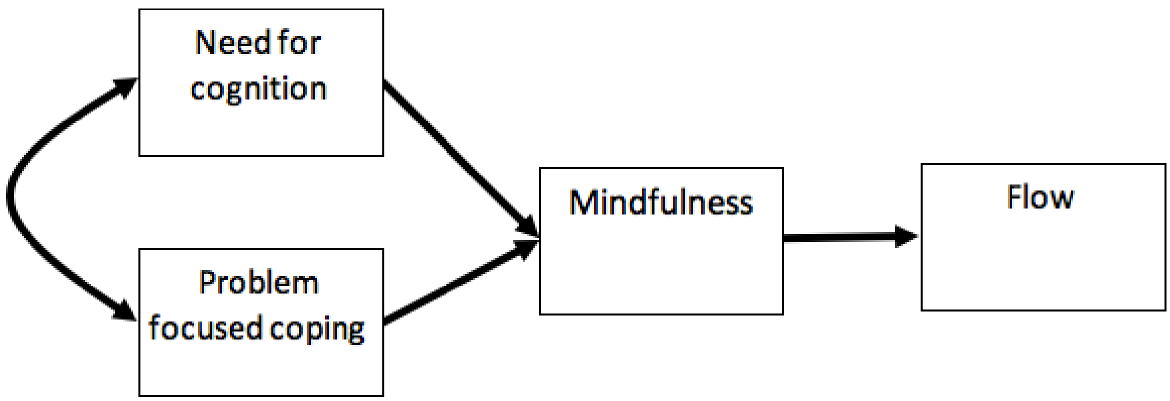

Figure 5.1: *Conceptual Model Predicting Flow.*

5.3.3 Methods

Participants

A battery of questionnaires was administered online to 107 people, which included 56 females and 51 males with an age range of 4.6% for 18-24, 58.7% for 25-34, 28.4% for 35-44, 8.2% for 45+. Participants were recruited from word of mouth through social media and electronic forums at Swinburne University of Technology, Australia. Work (N=53) and recreation (N=54) was assessed by determining the person's occupation and whether they typically experienced flow during their occupation or recreational activity. The study was approved by the authors' institutional ethics committee.

Behavioral Measures

Upon commencement of the study, participants were briefed and then received a battery of questionnaires including a short questionnaire designed to inform the researchers of participants' basic details, as well as their dispositional flow, mindfulness, active coping and need for cognition traits in order to best understand the underpinnings of their predispositions towards cognitive strategies that explain their predisposition to flow.

Participants were initially given the Dispositional Flow Scale-2 (DFS-2). The DFS-2 (Jackson & Eklund, 2002) is based in Csikszentmihalyi's (1990) flow concepts and quantifies the frequency people typically experience elements associated with flow states while involved in their flow activity. The DFS-2 has participants score on a five-point Likert scale ranging from 1 - "never" to 5 - "often", the frequency of their thoughts and feelings associated with flow while performing the task they most often experienced flow during.

Dispositional mindfulness - acting with awareness was measured as a subcomponent of the Five Facet Mindfulness Questionnaire (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). Participants were asked to indicate using a five-point Likert scale, ranging from 1 - “never or very rarely true” to 5 - “very often or always true”, their frequency of participating in different aspects of mindful behaviours. Internal consistency (α = .72 to .92) for the five elements ranged from adequate to good, as well as for the summed score (α = .93) (Bränström, Kvillemo, Brandberg, and Moskowitz, 2010). Additionally, Lykins and Baer (2009) conducted mediational analyses using the FFMQ.

The Need for Cognition (NFC) is assessed using a 34-item scale (Cacioppo & Petty, 1982). Participants were asked to indicate on a 5-point Likert scale ranging from 1 – “extremely uncharacteristic of me” to 5 – “extremely characteristic of me”. An aggregate score is based on all questions. Scale reliability and validity has shown high levels of stability (α = .90) (Cacioppo and Petty, 1982).

The Brief COPE (Carver, 1997) was assessed using 28-item scale and measures the ways people cope with stress in their lives. Participants were asked to indicate on a 4-point Likert scale ranging from 1 – “I haven't been doing this at all” to 4 – “I've been doing this a lot”. Administration instructions ask subjects to consider how they typically respond to problematic and stressful events in their typical flow activity.

Statistical analysis

A structural equation model was used to test the conceptual model in Figure 1 on the total sample, followed by a multi-sample covariance structure model across those reporting that flow mostly takes place in a work or recreational context. MPlus Version 8.4 was used to calculate all parameters, and missing values (n = 3) for the dependent variables were estimated using Mplus's Bayesian analysis (Muthén, Muthén, & Asparouhov, 2017). There were two multivariate outliers in the recreational groups which were deleted from the analysis. The Satorra-Bentler robust maximum likelihood estimator was used to account for multivariate non-normality and the parameter to case ratio was 16:105 or 1:8.75. Models were tested separately for each activity followed by a multi-sample analysis to assess model fit across work and leisure contexts. All descriptive statistics and correlation coefficients were computed in SPSS Version 26.

5.3.4 Results

The descriptive statistics in Table 5.1 show that although means of all variables were equal across the two activities, the patterns of associations were different. Increased flow was associated with increased mindfulness and need for cognition in work but not recreational activities. Increased coping was not significantly associated with increased flow in work related activities but was when the activity was recreational. Additionally, a one-way ANOVA determined that there was no difference between flow scores experienced between work (M=4.10, SD=0.51) and recreation (M=4.06, SD=0.47).

Table 5.1: *Zero Order Correlations and Descriptive Statistics for all Variables by Activity*.

	Flow	Mindfulness	Need for cognition	Coping
Total sample				
Flow	1			
Mindfulness	.29**	1		
Need for cognition	.28**	.58***	1	
Coping	.25*	.61***	.51***	1
Across activities				
Flow	1	.22	.26	.35***
Mindfulness	.37**	1	.57***	.41**
Need for cognition	.32*	.59***	1	.51***
Coping	.17	.76***	.53***	1
Work				
Mean	4.10	2.94	3.58	5.68
SD	.51	1.14	1.01	2.28
n	53	53	53	53
Recreational				
Mean	4.06	3.18	3.64	5.70
SD	.47	.89	.64	2.18
n	54	54	54	54
Total sample				
Mean	4.08	3.07	3.62	5.71
SD	0.49	1.02	0.84	2.22
n	108	108	108	108

Note. Correlations in the bottom diagonal are for work and the top diagonal are for recreation. * = $p<.05$, ** = $p<.01$, *** = $p<.001$. Independent t-tests revealed all means were not significantly different across activity.

Model testing

The conceptual model in Figure 5.2 was first tested on the entire sample, and revealed a reasonable fit with the data, $\chi^2(2) = 2.99$, $p = .224$, CFI = .97, TLI = .94, RMSEA = .07, SRMR = .06. The parameter estimates shown in Figure 5.2 reveal that mindfulness was the most proximal and significant predictor of flow. Both increased NFC and coping were significantly associated with higher mindfulness. The indirect effects for NFC and coping on flow via mindfulness were not significant, though both neared significance at $p = .060$ and $p = .051$ respectively. However, the modification indices (MI's) did not suggest that the inclusion of direct effects from either NFC or coping to flow would improve the model.

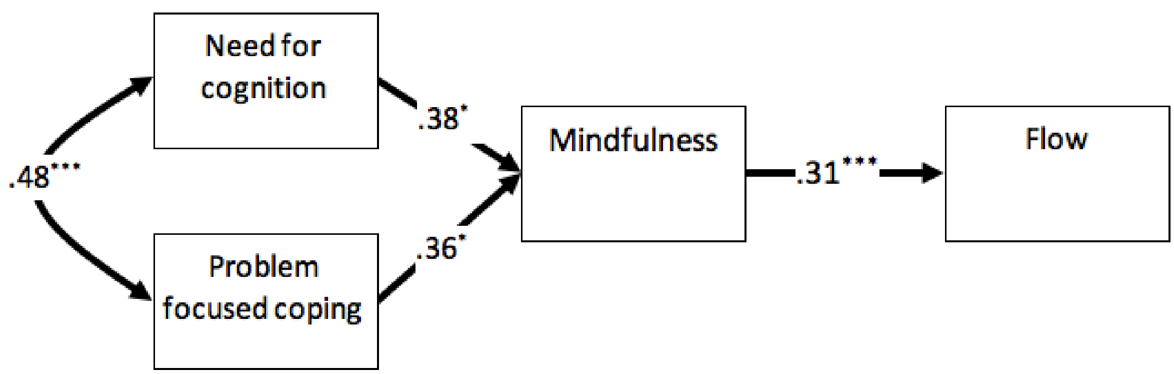

Figure 5.2: *Standardised Parameter Estimates for the Model Predicting Flow for the Total Sample.*

Note. Bolded standardised coefficients are for work and unbolded are for recreational. * = p<.05, ** = p<.01, *** = p<.001.

Initial testing of the conceptual model in Figure 5.3 separately for work and recreation suggested a direct effect of cope to flow for both activities. As coping may directly influence flow regardless of the level of mindfulness this path was included in the model. The results of an unconstrained multi-sample model revealed that for the sample overall, the model including a direct effect from coping was not ideal, $\chi^2(2)$ = 5.054, p = .080, CFI = .96, TLI = .79, RMSEA = .17, SRMR = .06. The contribution to the chi-square suggested that the model was a better fit for work (χ^2 = 1.47) than recreation (χ^2 = 3.58). The MIs suggested that for recreation, a direct effect between NFC and flow should also be included (MI = 3.52). Thus, this path was included in the model (for recreation only), resulting in a reasonable fit with the data, $\chi^2(1)$ = 1.86, p = .173, CFI = .99, TLI = .88, RMSEA = .13, SRMR = .03. The parameter estimated from the unconstrained model are shown in Figure 5.3.

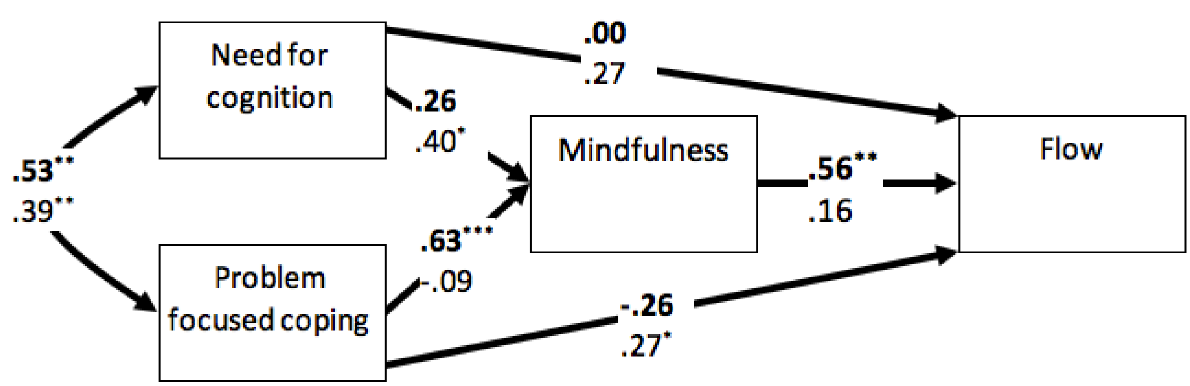

Figure 5.3: *Results of the Multi-Sample Model Predicting Flow*

Note. Bolded standardised coefficients are for work and unbolded are for recreational. * = p<.05, ** = p<.01, *** = p<.001.

The results in Figure 5.3 suggest that predictors of flow depend upon the nature of the activity. For work, mindfulness is a significant and strong direct predictor of flow, fully mediating the effect of coping. The indirect effect of coping on flow via mindfulness was significant (Standardised indirect effect = .35, p = .008) suggesting that coping tends to increase flow experienced in work activities because it increases mindfulness. The indirect effect of NFC on flow was however not significant (p = .13) and in a work context neither coping or NFC had a direct impact on flow.

Interestingly mindfulness was not important in predicting flow for recreational activities. The only variable found to significantly influence flow was coping. While increased NFC was associated with increased mindfulness in a recreational context, this effect did not transfer onto increased levels of flow (Standardised indirect effect = .06, p = .223). The direct effect of NFC on flow was also not significant, though it neared significance at p = .058. Thus, the results suggest that the significant zero order correlation (i.e. total effect) between NFC and flow is due to coping.

5.3.5 Discussion

This study's main objective was to explore the role of key cognitive strategies people are predisposed to in order to better determine the role personality plays in facilitating flow states. Overall, the study showed support for mindfulness as the most proximal predictor, mediating the impact of need for cognition and coping on flow. A key function of mindfulness results in improved self-regulation via decreased automaticity of mental processes. Unlike active cognitive states like problem solving coping and NFC, the process of automaticity can mold awareness of present day experiences based on unconscious and engrained states (Siegel, 2007).

Mindfulness has been shown to facilitate active coping strategies by utilizing improved self-observation, which has been shown to enable the creation of new skills, develop awareness of cognitive and emotional events as well as anticipating threats that can encourage an effective application of learned coping strategies (Baer, 2003). Furthermore, Kee and Wang (2008) showed that people who have a predisposition to higher mindfulness tend to be more likely to experience flow. Furthermore, flexibility shows similarities to active coping as it describes how a person actively manages their perceptions of challenges which is believed to help inform the relationship between mindfulness and flow states.

The relationship reported in this study between mindfulness and NFC has also been shown in several studies to be correlated with NFC across different contexts such as attitudinal ambivalence (Haddock, Foad, Windsor-Shellard, Dummel, & Adarves-Yorno, 2017) and wellbeing constructs (Brown & Ryan, 2003). Strategies improving mindfulness have been shown to be effective for people who are high on the NFC due to high NFC people engaging in cognitive activities (Cacioppo, Petty, & Feng Kao, 1984). Together, it can be seen how these predispositions are mediated by the underlying influence of mindfulness and its impacts on flow, especially as we have seen such a large array of positive correlations between flow and mindfulness in studies ranging from athletes (Love et al., 2019), meditation (Moore, 2013) and creative insight (Ovington, Saliba, & Goldring, 2018)

These findings further supported the hypothesis within the setting of work by mirroring much of what was described in the overall study in which mindfulness was shown as a mediator for flow during work. While a significant indirect effect was shown for coping, NFC however only trended to significance ($p=0.063$) in its correlation with mindfulness. This trend could be due to the smaller sample size of the bifurcated groups or rather NFC may play a smaller role in regard to flow in work contexts compared to coping. It makes sense that coping is associated more strongly with mindfulness, which in turn explains a greater amount of flow in work due to the greater amount of stress that may be present in work compared to leisure. Thereby part of the skill is to manage the amount of stress being presented during the workday. A meta-analysis conducted on the role of mindfulness in the workplace showed that trait mindfulness benefited job satisfaction as well as work performance (Mesmer-Magnus, Manapragada, Viswesvaran, & Allen, 2017).

As work can be stressful it is important that a person has a sense of their skill at work in order to be able to match the challenges presented throughout the workday. Bakker and van Woerkom (2017) showed that flow at work was influenced by Deci and Ryan (1985) self-determination theory, in which skills relate to the personal resources that an employee has to manage challenges at work. Workers that utilize their personal resources to initiate active strategies can contribute to flow. In particular, strategies such as active coping have been shown to facilitate personal resources such as optimism which has been shown to invest considerable effort in work tasks to satisfy basic needs that have a positive impact on flow (Beard, Hoy, & Hoy, 2010). In addition, coping explained much more of the variance in mindfulness in a work context, which in turn was much more highly predictive of flow.

Interestingly, the model for flow in recreational activities showed mindfulness presented no mediating effect or significant correlation with flow at all. This finding contradicts nearly every study on flow and mindfulness as far as the authors are aware, which have all presented significant positive correlations between these two factors (Cathcart et al., 2014; Glass, Spears, Perskaudas, & Kaufman, 2019; Love et al., 2019; Moore, 2013; Ovington et al., 2018). This finding could however be due to the difference in the level of recreational task skill. For instance, Gackenbach and Bown (2011) showed that the level of skill of gamers dictated performance and level of trait mindfulness and therefore it would be important to determine the level of recreational skill in order to better understand the relationship of mindfulness and flow in recreational tasks.

Furthermore, as mentioned earlier, Csikszentmihalyi (1990) suggested the experience of flow depends on intrinsic and extrinsic motivations. The majority of recreational flow tasks in this study were video games and may have a greater reliance on competitiveness than the work flow tasks. Love et al. (2019) reported that athletes whose motivation were competitive reported higher flow levels and Nicholls, Polman, and Levy (2010) showed that coping helps both with perceived performance as well as efficacy and anxiety in competitive sports. Therefore, it may be the competitive motivation of recreational tasks with different external pressures such as a lack of financial incentives that results in a reliance on a different type of predisposed cognitive strategy to occupational flow tasks.

Another difference in the model across contexts was that in relation to recreation, a direct relationship between active coping and flow was found. This coincides with findings from Asakawa (2010) who reported that Japanese students who partook in their hobbies were more likely to experience flow compared to those students who were less likely to experience flow and these high flow students were also more likely to utilize active coping styles such as problem solving. The relationship between flow states and autotelic personalities may further contribute to the role of active strategies in which Doron, Stephan, Maiano, and Le Scanff (2011) showed a positive relationship between students using active coping strategies that were intrinsically motivated. This may therefore support the inclination toward an intrinsic motivation to utilize active coping strategies to facilitate flow during recreational activities.

It may also be important to understand the level of expertise of the individual as it’s been reported that different levels of expertise result in different coping styles. A study showed expert athletes were more inclined to use more active task oriented coping styles than their less skilled counterparts (Gaudreau & Blondin, 2002). Therefore, it may be important to take skill level into consideration in future studies as participants finding flow in recreational tasks may have different levels of skill that could confound the data as to their predisposition to utilizing active coping strategies.

Furthermore, another consideration of this study may be why a person chooses to make their flow task professional or recreational. Do they require separation of financial incentives to ensure that the task remains autotelic or maybe they lack a sense of self confidence to make a professional career out of the flow task? These additional questions could also be considered in future studies.

The obvious limitation of the study was the low sample size and even though it was larger than most studies in this field, multiple factors trended toward significance. These trending factors would be more properly understood with larger sample sizes, especially when broken into the work/ recreation flow task split. Different results may have been obtained if flow tasks were grouped differently for analyses, for example, limiting the recreation task to something specific like video gaming. Furthermore, while the level of expertise may be more easily understood when considering a professional, it is less clear, yet still as important, to understand the level of expertise a person has in their recreational task as this may inform what type of cognitive strategies a person may be more inclined to utilize during their flow task. From this we can see particular shortcomings in the data, and it would be advantageous to gain greater insight about additional elements that may influence these results such as the level of skill a person may have in their recreational task. Future research in turn may want to explore the influence of different skill level to determine if this results in a change in frequency of achieving flow states as well as what other personality traits low and high skilled people partaking in recreational activities may be predisposed to implement in order to achieve flow. This may also be better detected using an experimental design where skill and other factors such as specificity of the task can be manipulated. This would also shed additional light on the process of flow under different conditions and help to clarify the direction of relationships between meditation, NFC and mindfulness.

Despite the limitations, this study was able to tease apart the interrelationships between mindfulness need for cognition and coping in terms of how they may influence flow, and in particular for flow in work. However, the mediation model further revealed a significantly different pattern of relationships for flow in recreational tasks suggesting mindfulness plays a lesser, and active coping a greater role in explaining flow states in this context. Future studies are needed however to clarify the role of expertise and specificity of the task to increase our understanding of the types of cognitive strategies individuals may rely on and when. This study may help guide this research in addition to the development of future interventions for optimizing access to flow states in tasks based on the type of task a person typically finds flow in based on the way they organize their lives.

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Chapter 6: Part 2 - The Neurocognitive Exploration of Flow States Using tDCS

6.1 Part 2 Introduction

Part 2 of this thesis addresses the second research question by utilizing a neurostimulation technology such as tDCS to help determine the neurocognitive functions of flow and improve induction of flow states for recreational and occupational participants. Part 2 looks at the neurocognitive exploration of flow states using tDCS by presenting work from two papers. The first explores the impact tDCS has as a modulatory technology on aspects of domain general expertise across occupational and recreational gamers. The second paper then addresses the impact tDCS has in assisting in the neurocognitive exploration and induction of flow states across occupational and recreational gamers.

6.2 Publication 4: Rationale

This paper presents the results from part 2 of the thesis looking at the role of tDCS in exploring the neurocognition of flow states. In particular, this paper begins by investigating the assistive role tDCS has in modulating the action observer network for in domain general expertise across both recreational and occupational gamers utilizing a soccer goalie temporal occlusion task. The research comprises of two experimental paradigms: 1) Performance accuracy, and 2) EEG. Performance accuracy is a good indicator for modulatory enhancement of neurostimulation, while an evoked response spectral potential from the EEG is useful in determining the changes in neurocognitive functioning.

While this paper has not been accepted for publication yet, it has been peer reviewed and provided with helpful comments. The reviewers' comments were addressed in the following paper which can be found in Appendix 2.

Gold, J. and Ciorciari, J. (2020) Impacts of transcranial stimulation on sports occlusion task and its frequency power profile, Journal of Sport & Exercise Psychology, (Submitted April 2020)

6.3 Publication 4: Impacts of transcranial stimulation on sports occlusion task and its frequency power profile

6.3.1 Abstract

Effective anticipation skills in sporting cognition have been shown to facilitate expertise in sports. Transcranial direct current stimulation (tDCS) has shown to improve motor and cognitive functioning. Therefore, this study aimed to determine the assistive effects of tDCS on the action observer network (AON) in both novice and expert gamers during an occlusion task as well as the related EEG spectral power response. 23 novice and 23 expert video gamers received either sham or active tDCS with a right parietal anode and left frontal cathode. Only experts demonstrated a significant improvement in predicting ball direction for the overall and early occlusions after tDCS. Spectral power results revealed significant changes in theta, high-gamma and delta frequencies. The findings indicate tDCS was able to modulate anticipatory behavior and cortical activity in experts compared to novice participants, suggesting a facilitatory role for tDCS to improve anticipatory effects and assist as a neurocognitive training technique.

6.3.2 Introduction

Certain sports with projectile balls such as baseball, tennis and cricket place extreme demands on visual processing systems to the point where player expertise comes down to the ability to anticipate the balls trajectory (Farrow & Abernethy, 2003). This was evidenced by the lack of processing time available after a ball's release, as the majority of the decision about the balls trajectory needs to be based prior to this event (McLeod, 1987). Sports researchers have created a range of different occlusion tasks, where participants view the opponent's action then categorize the action, such as the direction of a soccer kick, or determine the outcome to simulate this anticipatory decision making based on a similar lack of visual processing information. The view is cut off (temporal occlusion) at a particular time point to limit perceptual cues. When the removal of a specific perceptual cue results in a measurable decrease in the expert's performance advantage they have over novices, then the occluded information is considered relevant to the experts' perceptual advantage (Williams, Ward, Smeeton, & Allen, 2004). In a typical temporal occlusion study, visual cues of the opponent's action are limited at different points during the task. For example, a soccer kick video clip from the goalie is stopped before the ball is kicked and then again shortly after kicked. Occlusion studies were performed on tennis players with varying levels of expertise and were required to determine the type of serve during occluded video clips. The expert tennis players were better able to determine the serve type with less visual cues compared to novices (Scott, Scott, & Howe, 1998). This effect has been shown to the point where experts performance is much better than novices also at earlier occlusions compared to late occlusions (Jackson, Warren, & Abernethy, 2006).

It is assumed that predicting the final action of an observed sequence is reliant on the action observer network (AON) to predict the future behaviour and respond accordingly based on visual analysis of the action, as well as visuomotor and sequence learning (Cross, Kraemer, Hamilton, Kelley, & Grafton, 2008). Neuroimaging studies have identified a bilateral network within frontal premotor, parietal, and temporo-occipital cortex (Caspers, Zilles, Laird, & Eickhoff, 2010). In particular, the frontoparietal network has been shown to be a dynamic control system that provide predictive computations (Avenanti, Annella, Candidi, Urgesi, & Aglioti, 2012), which has been seen throughout the temporal occlusion literature including hockey (Wimshurst, Sowden, & Wright, 2016), tennis (Wright & Jackson, 2007), and soccer (Bishop, Wright, Jackson, & Abernethy, 2013) to name a few.

Theta-frequency oscillations within the frontoparietal network have been associated with enhanced reactive and proactive cognitive control processes in visual working memory tasks, such as modifying behaviour responses during goal-conflict (Sauseng et al., 2006). Optimized application of cognitive control processes have been shown to maintain sustained and anticipatory attention of goal-relevant information to afford optimal cognitive performance (Braver, 2012). Parietal theta has been shown to peak earlier and feed-forward through to frontal sites during goal-directed anticipatory tasks (Cooper, Wong, McKewen, Michie, & Karayanidis, 2017) and visuospatial selective-attention processes (Green & McDonald, 2008). With research evidence now highlighting the importance of the role of the frontoparietal network, with particular importance on theta activity, in association with the AON for enhancement of temporal occluded performance, there is an opportunity to further test this using non-invasive stimulation techniques.

Transcranial direct current stimulation (tDCS) has also been examined as a way to improve performance in normal subjects. tDCS is a non-invasive brain stimulation technique that modulates cortical excitability in a polarity-dependent manner: Anodal stimulation has been shown to increase excitability, whereas cathodal decreases it (Nitsche & Paulus, 2011). (Nitsche & Paulus, 2011). tDCS has also been examined as a means to enhance performance in normal subjects during visual working memory tasks and selective attention tasks (Clark et al., 2012). Expert athlete performers have been shown to rely more heavily on parietal region functioning compared to novices during occlusion tasks (Abreu et al., 2012; Yarrow, Brown, & Krakauer, 2009) suggesting a shift towards a superior attention strategy due to limited visual cues (Bishop et al., 2013). The parietal lobe has been shown to be a key component in the AON in general (Buccino et al., 2001), as well as providing predictive reasoning during action observation (Fontana et al., 2012). Right parietal anodal tDCS stimulation has been show to improve frontoparietal network connectivity (Hunter et al., 2015), object detection during visual search (Tseng et al., 2012) and spatial attention (Roy, Sparing, Fink, & Hesse, 2015). More specifically, Clark et al. (2012) showed improved learning outcomes for implicit motor tasks in detecting concealed objects, which resulted in greater neural efficiency through an improved task learning performance.

Posner and Petersen (1990) gave emphasis to the lateral frontal cortex for its relevance to the frontoparietal attention network and its role in acquiring attention during target detection. Frontal left cathodal tDCS has resulted in performance improvements for accurate visual categorization (Lupyan, Mirman, Hamilton, & Thompson-Schill, 2012), cognitive flexibility (Chrysikou et al., 2013) and visual working memory (Fregni et al., 2005). Dockery, Hueckel-Weng, Birbaumer, and Plewnia (2009) was able to show a reaction time and accuracy improvement during the early learning phase of a working memory task due to its inherent ability to limit the role of preconceived verbal-analytic control (Luft, Zioga, Banissy, & Bhattacharya, 2017) that was believed to lead to an enhanced encoding of the location of the target during visual search and, therefore, greater accuracy. Several occlusion studies have shown novices rely more on executive decision-making processes in the prefrontal region compared to experts who utilize more posterior regions (Abreu et al., 2012; Olsson & Lundström, 2013). Additionally, a recent tDCS study by Gold and Ciorciari (2019) was able to show that a cathodal left prefrontal and anodal right parietal tDCS was able to improve performance scores in a visual working memory task for both novices and experts in a domain specific task..

In order to gain a better understanding of the role of the frontoparietal network on the AON, tDCS was employed to test the effectiveness of performance modulation using a soccer occlusion task for people that are experts and novices in videogaming, but not in the soccer task itself, while EEG assessed the modulated role of theta. It was hypothesized that a left frontal cathode/ right parietal anode stimulation montage would result in an improvement of ball direction prediction accuracy for both experts and novices gamers as well as an increase in theta activity. It is for the lack of expertise in the task itself that parietal regions were excited rather than motor regions due to a lack of soccer motor representations. An additional focus of the study was on the impact of tDCS on the frontoparietal AON by testing at different temporal occlusion times (early vs late occlusion) to determine the extent of performance ceiling effects and AON differences between expertise. Again, it was hypothesized that there would be an improvement of ball direction prediction accuracy for both expert gamers and novices. A final component of the study is to investigate an enhanced theta modulatory effect associated with improved successful anticipation scores after tDCS modulation, compared to sham, of the frontoparietal AON for both novice and expert gamers.

6.3.3 Methods

Participants

Twenty-three right-handed novice gaming participants of which eleven were male (M = 31.8 years, SD = 3.61) and twelve were female (M = 30.18 years, SD = 6.14). Participants were identified as untrained gamers on a questionnaire who stated on average they played videogames less than once a month. Additionally, twenty-three right-handed expert gaming males (M = 29 years, SD = 7.15) who rated themselves as having a strong aptitude for first-person shooter games and indicated frequent game use of several times a week. The study was ethically approved as per NHMRC guidelines. Individuals were recruited via game forums and by word of mouth at Swinburne University of Technology, Australia. All subjects gave their informed consent prior to participating in the study. Participants were randomly assigned between active and sham tDCS stimulation conditions. It was a requirement for participation that subjects had some understanding of the game Tetris in which 100% of participants indicated sufficient aptitude.

Occlusion Task

A pre-and post-test design was used to test before and after the tDCS intervention using a soccer goalie kicking temporal occlusion test as a video simulation based on a test developed by Müller, Abernethy, and Farrow (2006). Testing was performed for both expert and novice videogaming participants. The purpose of the video soccer simulation test was to examine the capability to use domain-general advanced information from the AON and determine if a tDCS intervention could improve the accuracy of detecting kicking direction scores. Each participant watched footage of different people kick a soccer ball toward them until a temporal occlusion occurred and the participant then indicated using arrows on the keyboard one of three different directions the ball was being kicked. The two temporal occlusion conditions included either before or after the foot kicked the soccer ball. The video simulation test included 26 randomized trials consisting of three kick types (screen left, center and right) x two temporal occlusion conditions (early and late) at two intervals (before and after stimulation or sham conditions). See Figure 6.1 for a diagram of the experimental setup.

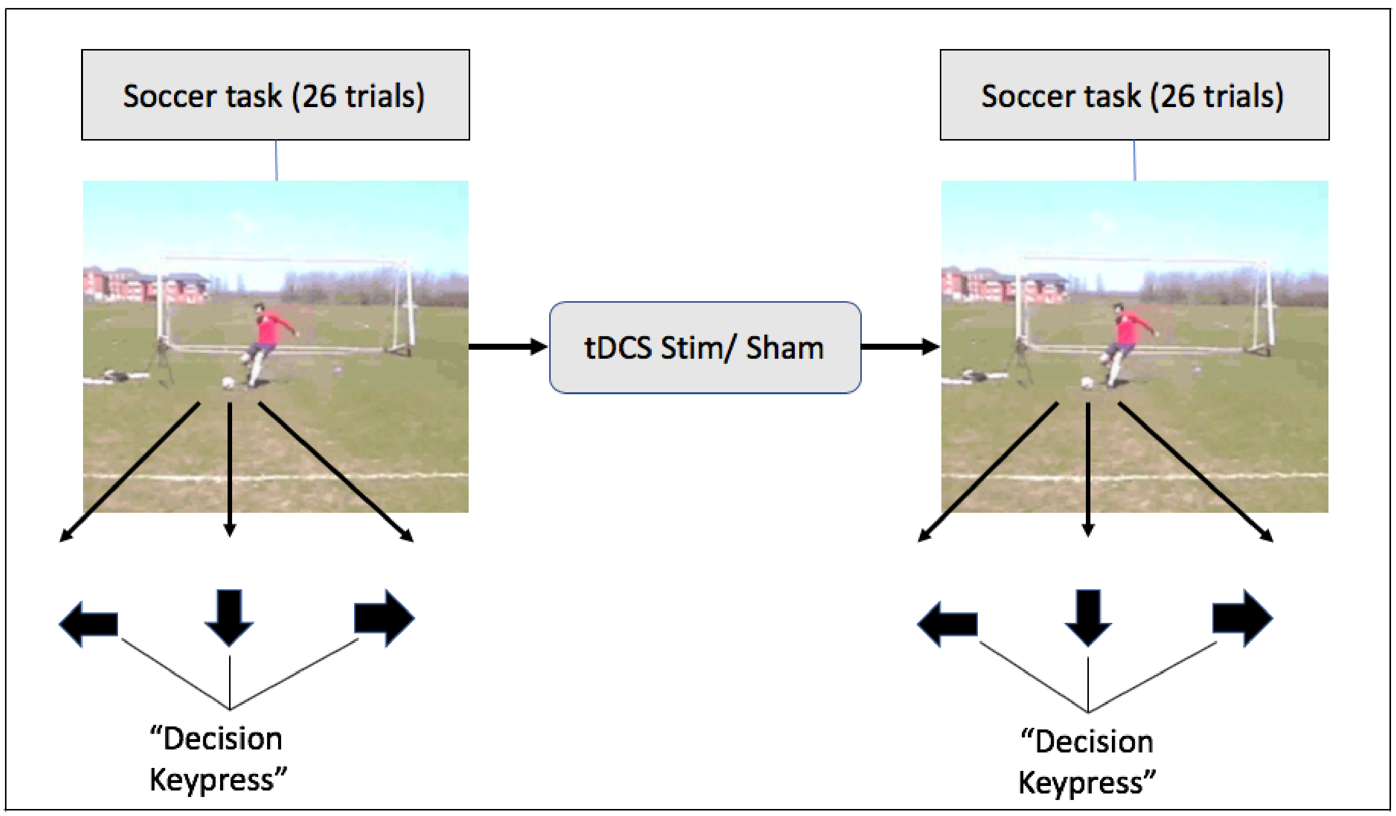

Figure 6.1: Experimental setup of soccer goalie occlusion task before and after tDCS.

Neurostimulation

TDCS was applied using a NeuroConn DC-Stimulator (NeuroConn GmbH) machine with a montage of left prefrontal cathode and right parietal anode. For each novice and expert group, 12 participants randomly received sham and 11 received tDCS stimulation. tDCS was applied with two 5cm × 5cm saline-soaked sponge electrodes. The stimulation site was located using the 10/20 international system (Böcker, van Avermaete, & van den Berg-Lenssen, 1994). The anode was positioned near F3, and the cathode near P6. Whilst tDCS excitability changes have been shown to last up to 60mins (Nitsche & Paulus, 2001), results have shown performance effects dwindle after 30mins of stimulation (Iyer et al., 2005). Therefore, the stimulation condition was set for 20mins (including 10secs ramp-up and 10secs ramp-down time) at 2mA while sham condition also lasted 20mins but was set for 30secs of stimulation at 1mA. Participants are typically unable to determine whether they are receiving real or sham stimulation (Gandiga, Hummel, & Cohen, 2006).

Analysis

A 64-channel EEG was used at a sampling rate of 2048 Hz. Preprocessing of EEG data was performed with the Brainstorm toolbox for MATLAB (Tadel, Baillet, Mosher, Pantazis, & Leahy, 2011), which is freely available online under the GNU general public license (http://neuro-image.usc.edu/brainstorm/). A notch filter (60, 120, and 180 Hz) was applied along with a band-pass filter of 0.1–100 Hz to eliminate low and high frequency noises. Noises caused by eye blinks were also identified and excluded with the ICA (independent component analysis) decomposition in Brainstorm.

All EEG data was re-referenced with an average potential across the 64 electrodes. EEG waveforms were epoched from −500ms to 1000ms with 0ms relative to the onset of an occlusion.

Statistical Design

Using SPSS 27, a mixed Analysis of Variance (ANOVA) was used to determine a significant interaction effect from tDCS. Further, polynomial contrasts based on time with Bonferroni corrections were used for the post hoc analyses.

Evoked response spectral power (ERSP) analyses were run to determine changes in frequency power as measured by the time-frequency decomposition using the complex Hilbert transform (central frequency: 1 Hz, time resolution at full width at half maximum: 3secs). Statistical comparisons were made using Brainstorm statistical tools on the frequency mean differences between sham and active tDCS for expert gamers using independent 2-tailed parametric t-test for low frequency activity (delta 2-4 Hz & theta 5-7 Hz) and high frequency (gamma 30-59 Hz). T-test data cannot be exported from Brainstorm and hence analysis was not run on novice participants due to the limitation of Brainstorms statistical versatility and the fact that a non significant result was already ascertained through the behavioral data. Average spectral power at scalp electrode sites was obtained for both active and sham tDCS for expert gamers. Statistically significant differences ($p < .05$) in power spectra were plotted across the topography for the two stimulation conditions along with temporal t-scores across the period both pre- and post-occlusion event.

Experimental procedure

Experimental procedures were explained on arrival at the laboratory and were then fitted with an EEG cap using positional markers. The subject sat upright throughout the experiment in front of a screen. Participants began with a 3min baseline resting condition with eyes closed, relaxed breathing and hands resting on legs. They were then instructed to complete the soccer occlusion task. Afterwards, participants were setup for tDCS and randomly received the stimulation or sham condition for 20mins. Subjects were unaware of their assigned stimulation condition. Participants would again complete the 3min baseline condition and the soccer occlusion task after stimulation or sham. No participant reported experiencing adverse effects during or after tDCS. A slight itching sensation during approximately the first 30secs of stimulation was reported. The sham condition reported the same initial itching sensation, and when explicitly asked, believed to have undergone real stimulation.

6.3.4 Results

Behavioural

An overall main effects was observed for all participants using an Analysis of Variance (ANOVA) ($F[1, 44]=13.72$, $p < 0.01$, $n^2=0.24$) in which videogaming experts (M=10.61, SD=2.39) in general scored more correct responses than novices (M=8.35, SD=2.21) despite neither group having done the task before. A mixed ANOVA was used to determine a significant interaction effect from tDCS ($F[1, 44]=4.64$, $p < 0.05$, $n^2=0.10$) (Figure 6.2), in which the sham condition only improved on average by ($\Delta M=0.63$) compared to the active condition which improved on average by ($\Delta M=2.36$). See Table 6.1 for means and SD's for tDCS accuracy effects on the combined novice and expert group scores.

Table 6.1: Means and SD's for the combined novice and expert group scores for the overall and early occlusion sets before (Pre-Stim) and after (Post-Stim) stimulation.

Group	Occlusion	Trial	Stimulation	M	SD
Combined	Overall	Pre-Stim	sham	9.79	2.41
			active	8.57	2.58
			Total	9.22	2.54
	Early	Pre-Stim	sham	5.63	1.74
			active	4.86	1.75
			Total	5.26	1.77
	Overall	Post-Stim	sham	10.42	2.65
			active	11.10	2.39
			Total	10.73	2.53
	Early	Post-Stim	sham	4.38	1.44
			active	5.14	2.03
			Total	4.74	1.77

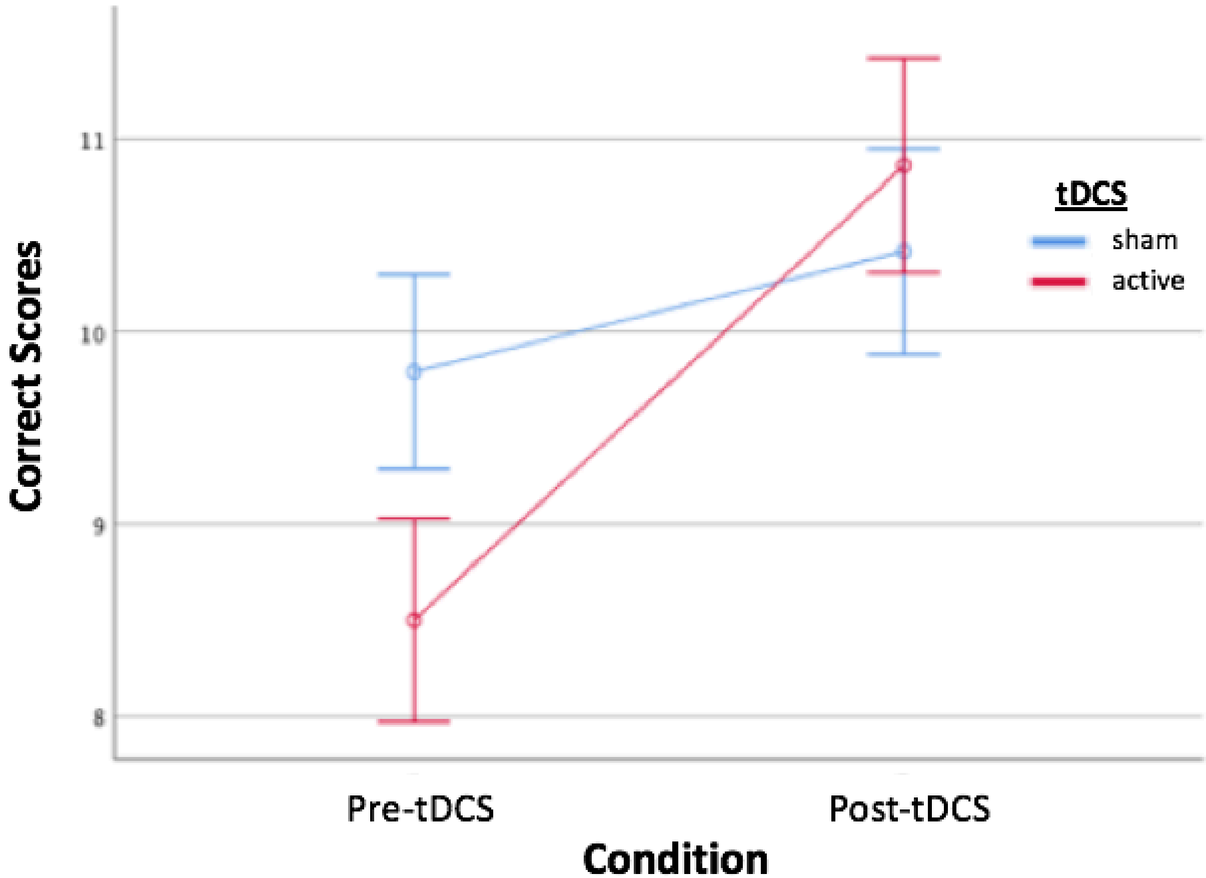

Figure 6.2: Combined novice and expert gamer correct scores of occluded soccer kicks for pre and post tDCS active and sham conditions. Bars – Standard Error.

Subjects were then split into expert and novice groups in which another mixed ANOVA was used to determine a significant interaction effect only for the expert group ($F[1, 21]=6.20$, $p < 0.05$, $n^2=0.23$) (Figure 6.3) compared to a non-significant interaction for the novice group (Figure 6.4). The sham condition for experts performed on average only slightly better ($\Delta M= 0.09$) compared to the active condition which improved on average by ($\Delta M=3.09$). See Table 6.2 for means and SD's for tDCS accuracy effects on the individual novice and expert group scores.

Table 6.2: Means and SD's for the individual novice and expert group scores for the overall and early occlusion sets before (Pre-Stim) and after (Post-Stim) stimulation.

Group	**Occlusion**	**Trial**	**Stimulation**	**M**	**SD**
Novice	Overall	Pre-Stim	sham	8.25	2.14
			active	8.20	2.97
			Total	8.23	2.49
	Early	Pre-Stim	sham	4.58	1.24
			active	4.70	1.83
			Total	4.64	1.50
	Overall	Post-Stim	sham	9.42	2.68
			active	10.10	2.28
			Total	9.73	2.47
	Early	Post-Stim	sham	4.00	1.48
			active	4.50	1.65
			Total	4.23	1.54
Expert	Overall	Pre-Stim	sham	11.33	1.56
			active	8.91	2.26
			Total	10.17	2.25
	Early	Pre-Stim	sham	6.67	1.56
			active	5.09	1.81
			Total	5.91	1.83
	Overall	Post-Stim	sham	11.42	2.31
			active	12.00	2.19
			Total	11.70	2.23
	Early	Post-Stim	sham	4.75	1.36
			active	6.00	2.00
			Total	5.35	1.77

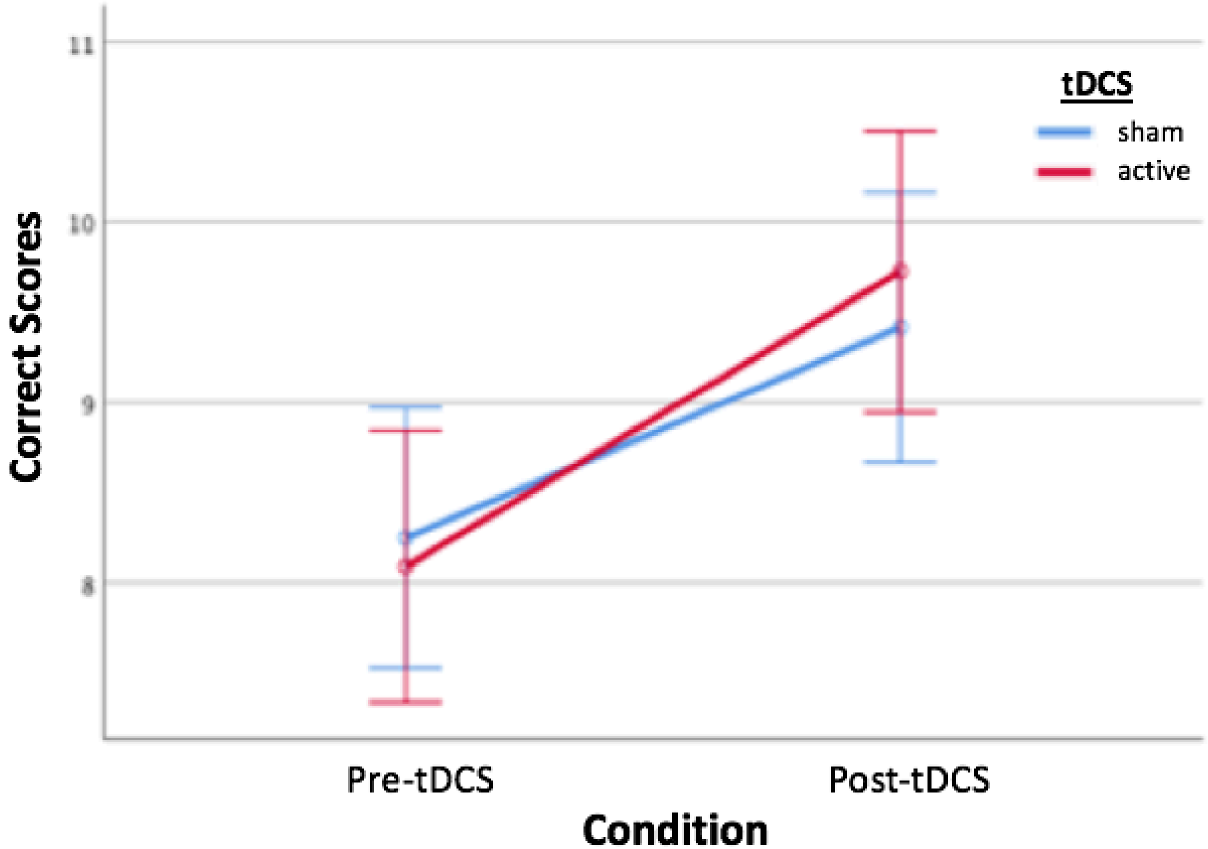

Figure 6.3: Novice gamer correct scores of occluded soccer kicks for pre and post tDCS active and sham conditions. Bars – Standard Error.

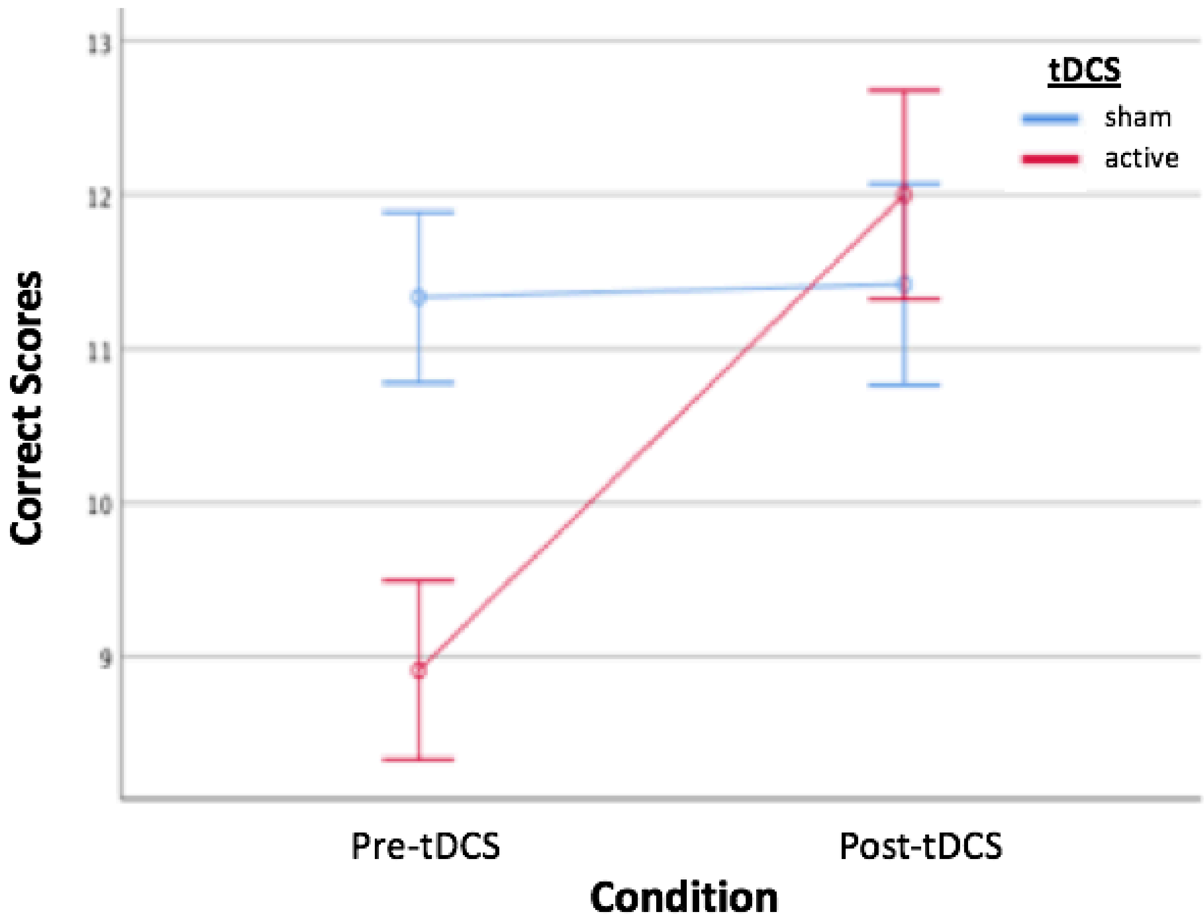

Figure 6.4: Expert gamer correct scores of occluded soccer kicks for pre and post tDCS active and sham conditions. Bars – Standard Error.

Additionally, different occlusion times (early and late) showed only a significant interaction effect ($F[1, 44]=5.83$, $p < 0.05$, $n^2=0.12$) for the early occlusion condition (Figure 6.5) in which sham performed worse on average ($\Delta M = -1.25$) compared to the active condition which improved on average ($\Delta M= 0.28$). Subjects were then split into expert and novice groups in which another mixed ANOVA was used to determine a significant interaction effect only for the expert group ($F[1, 21]=6.88$, $p < 0.05$, $n^2=0.25$) (Figure 6.6) compared to a non-significant interaction for the novice group (Figure 6.7).

The sham condition for experts performed on average worse (ΔM= -1.92) compared to the active condition which improved on average (ΔM=0.91).

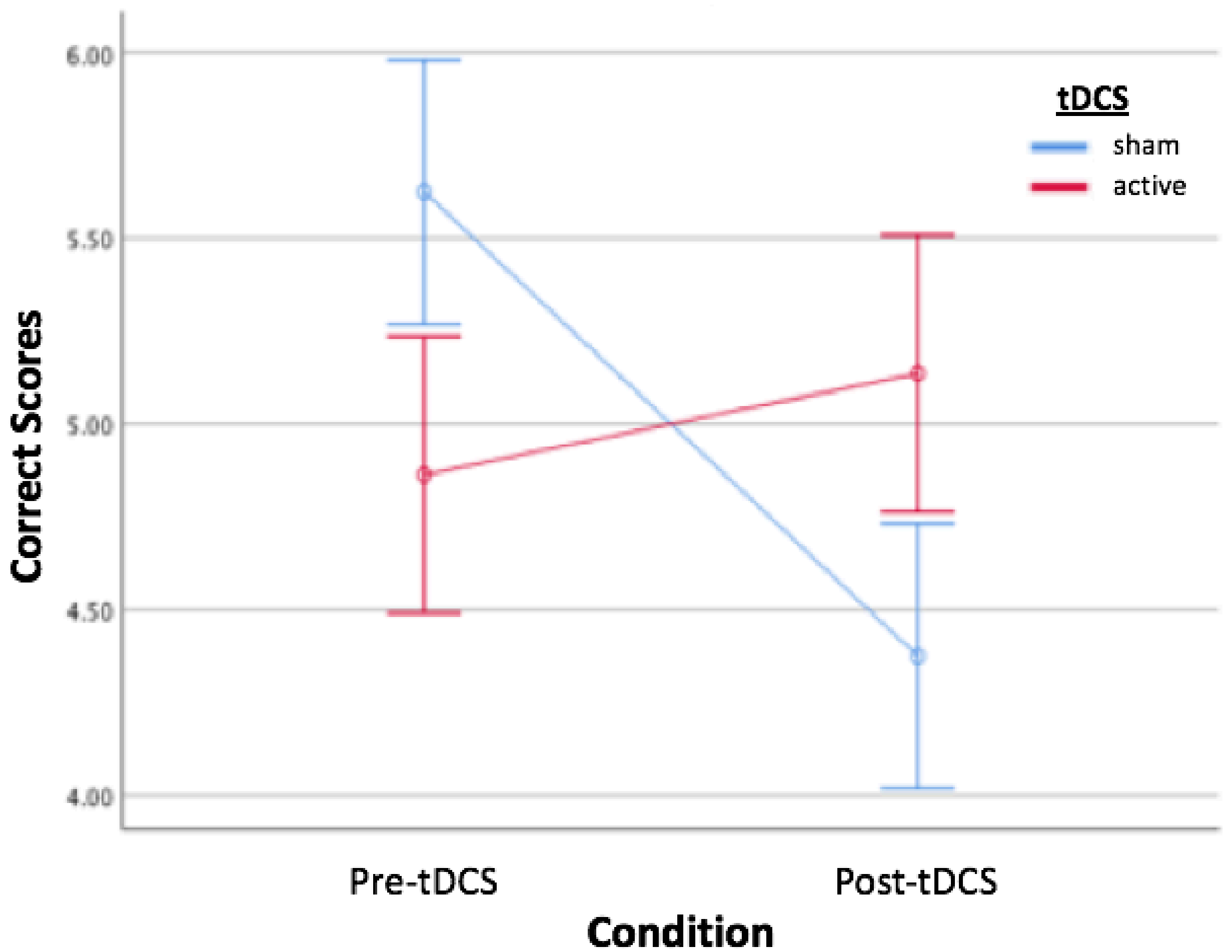

Figure 6.5: Combined novice and expert gamer correct scores of early occluded soccer kicks for pre and post tDCS active and sham conditions. Bars – Standard Error.

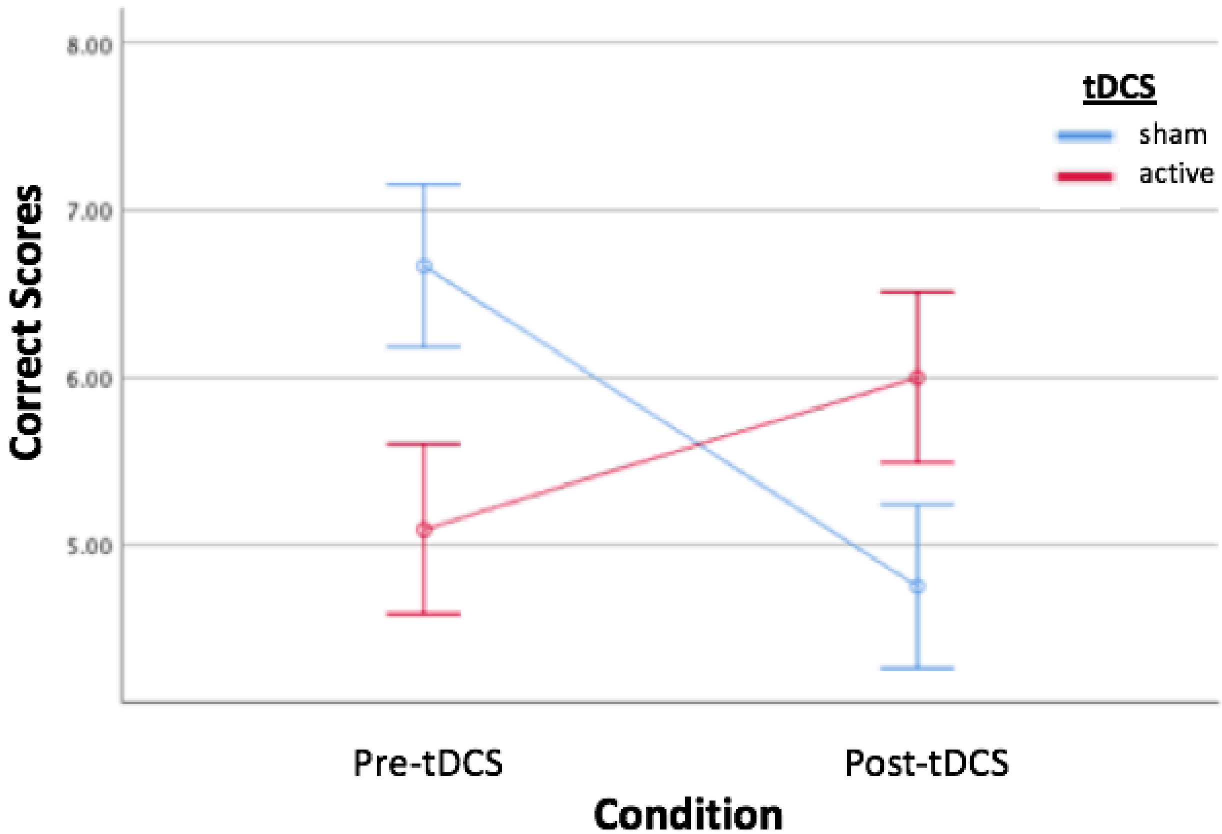

Figure 6.6: Expert gamer correct scores of early occluded soccer kicks for pre and post tDCS active and sham conditions. Bars – Standard Error.

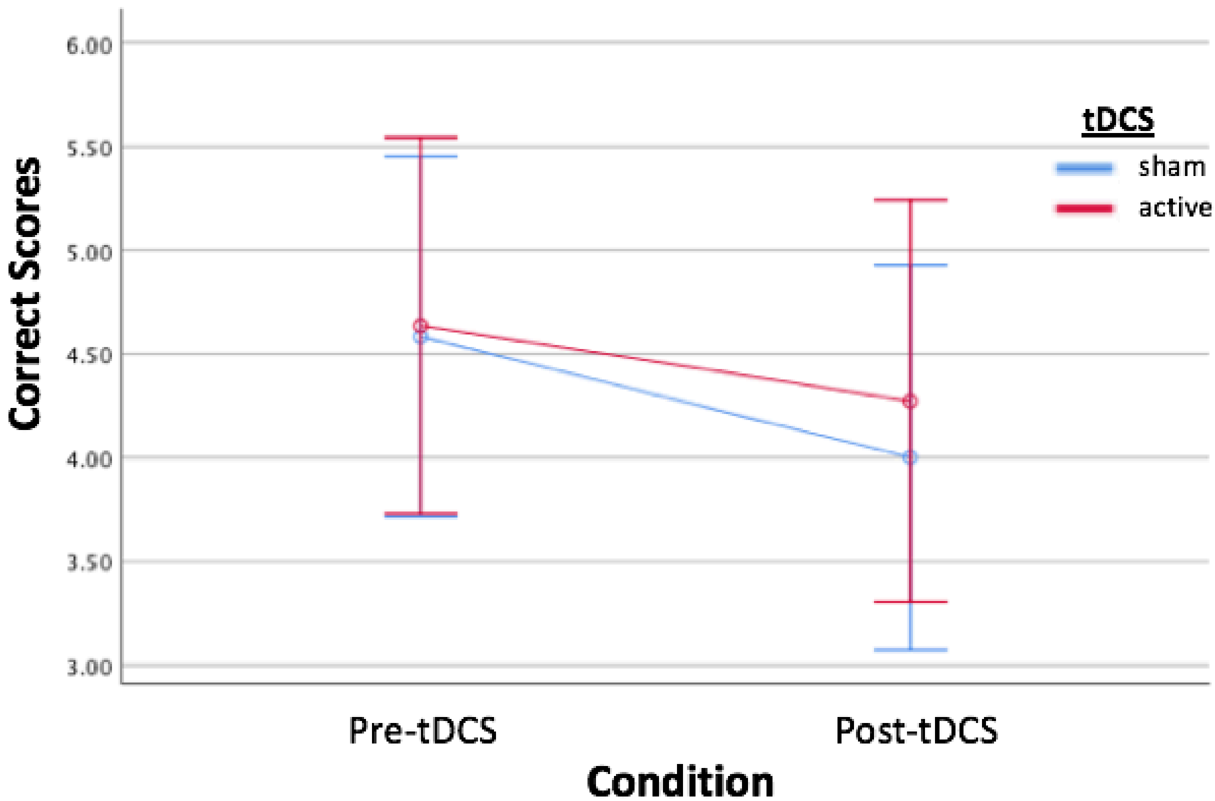

Figure 6.7: Novice gamer correct scores of early occluded soccer kicks for pre and post tDCS active and sham conditions. Bars – Standard Error.

Topographical ERSP

To probe scalp sites showing frequency power differences, a theta topographical ERSP analysis compared across expert stimulated and sham groups over the entire scalp from -100ms to 0ms at point of occlusion. Novice gamers were not analysed as they did not show a significant performance change from the tDCS. Through the Brainstorm t-test statistical interface, scalp maps of t-scores showed a ($p<0.05$) significant difference with a stronger bilateral central posterior activation as well as a bilateral frontal activation for expert stimulated gamers compared to sham tDCS. A time and scalp map of t-scores in the theta band are shown in Figure 6.8A and 6.8B, respectively. Additionally, an increased significant ($p<0.05$) posterior response was present for the whole 500ms prior to the occlusion point.

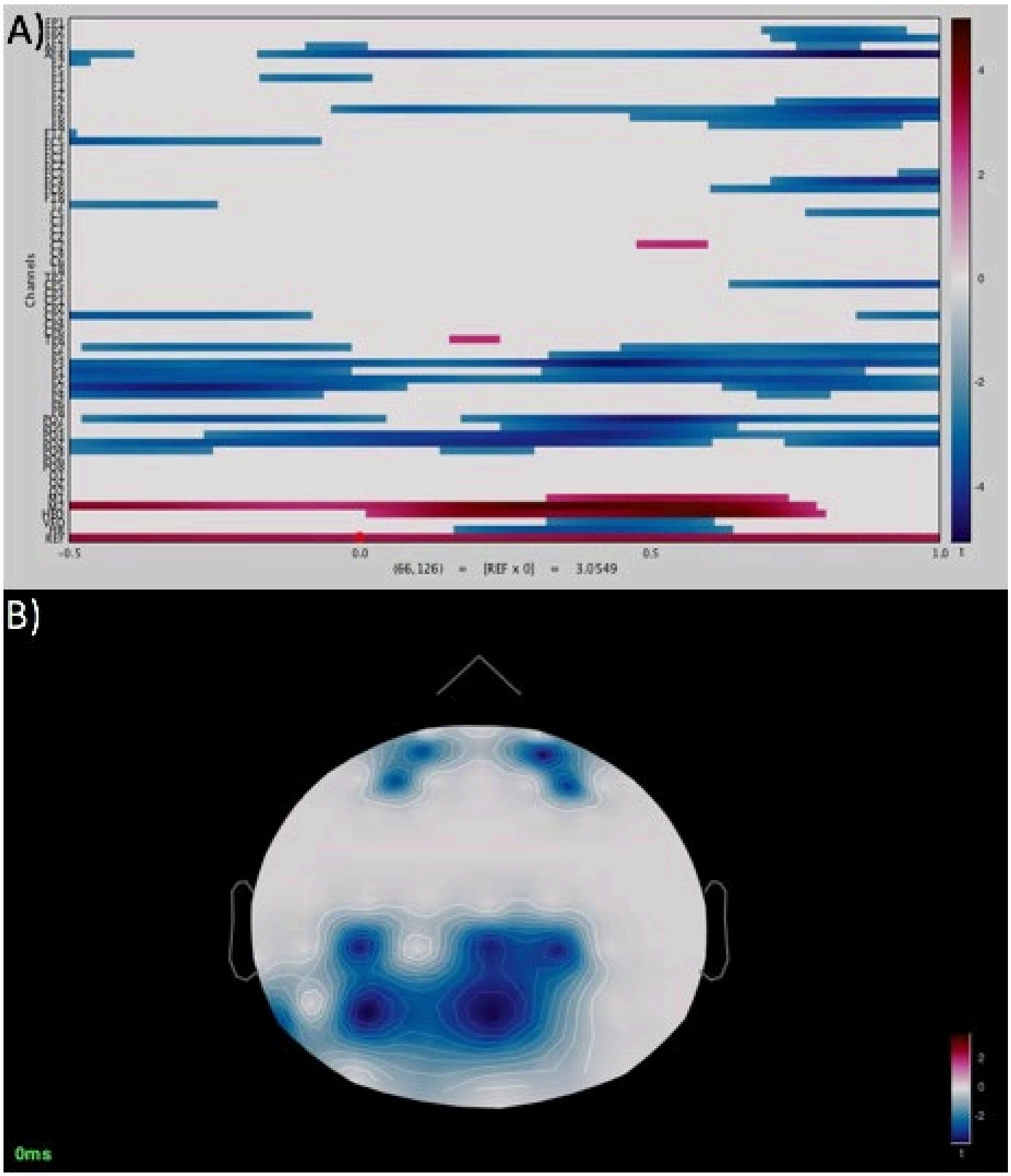

Figure 6.8: Statistical time map (-500ms to 1000ms; 0ms = occlusion point) of theta frequency analysis of significant t-score difference between tDCS (blue) and sham (red) expert gamers after stimulation. Deeper colours signify higher t-scores. B) Theta frequency scalp map of spectral power difference between tDCS (blue=>) and sham (red=>) expert gamers after stimulation at 0ms (occlusion point).

Furthermore, an ERSP power analysis was performed for high gamma, again from -100ms to 0ms at point of occlusion. Through the Brainstorm t-test statistical interface, scalp maps of t-scores showed a ($p<0.05$) significant difference across a strong bilateral frontal activation for expert gamers after tDCS compared to sham stimulation, with an additional stronger centro-posterior column activation occurring -50 ms to -20 ms prior to occlusion. A time and scalp map of t-scores in the high gamma band are shown in Figure 6.9A and 6.9B, respectively. Additionally, a significant frontal central response was present for the whole 500ms prior to the occlusion point.

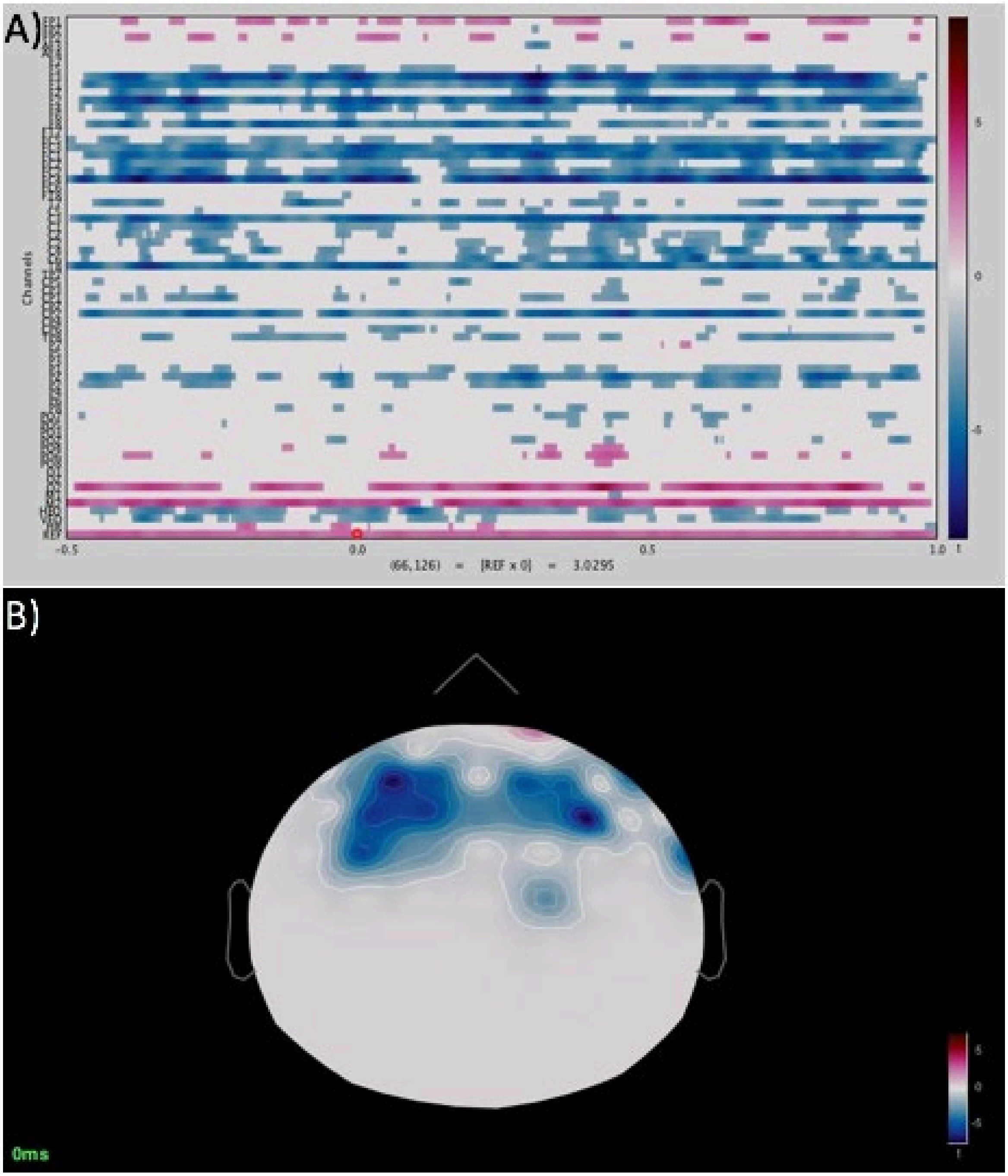

Figure 6.9: A) Statistical time map (-500ms to 1000ms; 0ms = occlusion point) of high gamma (60-99Hz) frequency analysis of significant t-score difference between tDCS (blue) and sham (red) expert gamers after stimulation. Deeper colours signify higher t-scores. B) High gamma frequency scalp map of spectral power difference between

tDCS (blue=>) and sham (red=>) expert gamers after stimulation at 0ms (occlusion point).

Finally, a topographical ERSP analysis was performed for expert gamers across delta frequency, also from -100ms to 0ms at point of occlusion. Through the Brainstorm t-test statistical interface, scalp maps of t-scores showed ($p<0.05$) a significant difference across a stronger bilateral posterior activation for expert gamers with tDCS compared to sham stimulation both prior and after occlusion. Additionally, a significant ($p<0.05$) left frontal response was present for the 150ms prior to the occlusion point for expert gamers with tDCS compared to sham stimulation. A time and scalp map of t-scores for delta band is shown in Figure 6.10A and 6.10B, respectively.

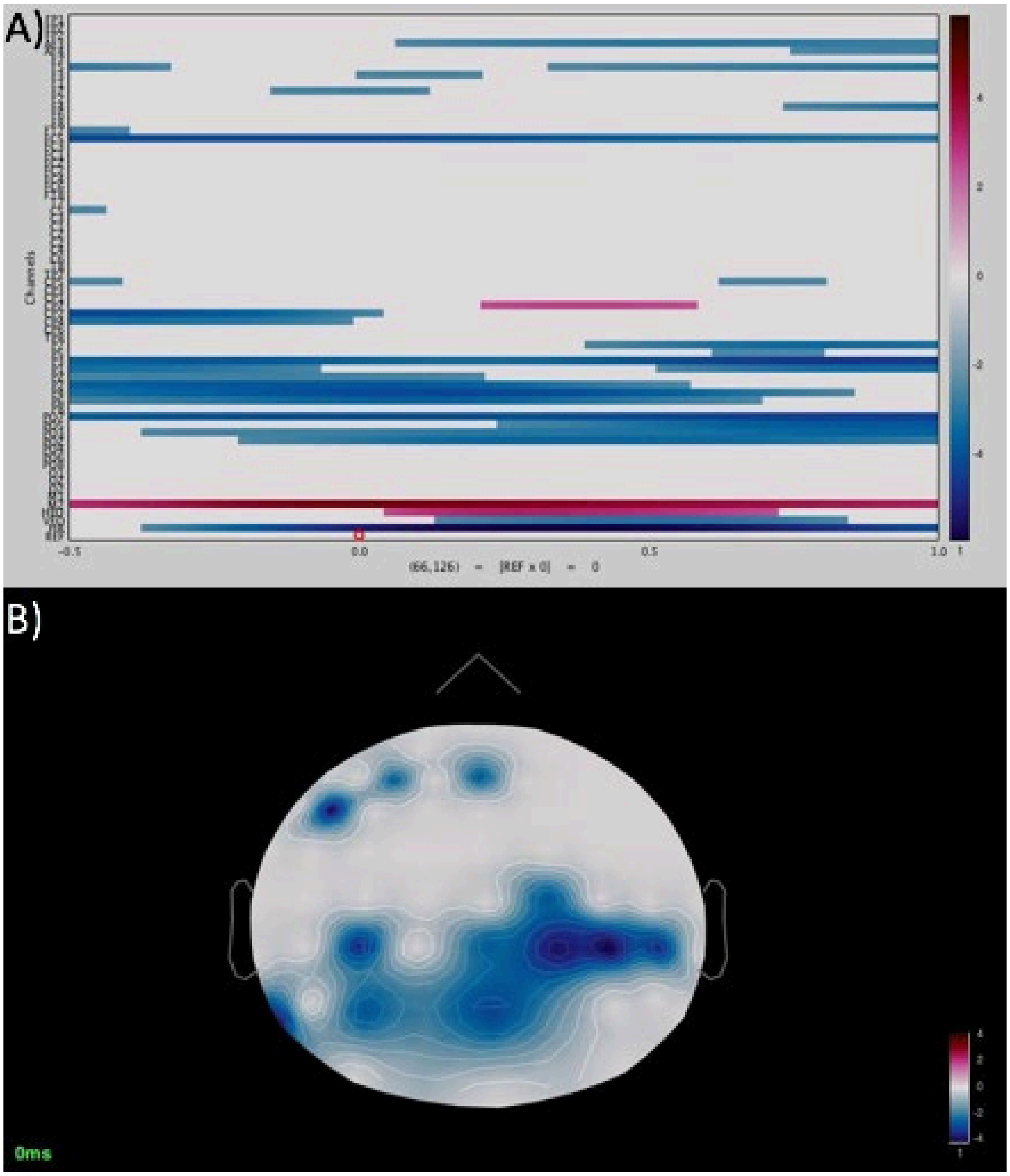

Figure 6.10: A) Statistical time map (-500ms to 1000ms; 0ms = occlusion point) of delta (2-4Hz) frequency analysis of significant t-score difference between tDCS (blue) and sham (red) expert gamers after stimulation. Deeper colours signify higher t-scores. B) Delta frequency scalp map of spectral power difference between tDCS (blue=>) and sham (red=>) expert gamers after stimulation at 0ms (occlusion point).

6.3.5 Discussion

This study investigated the effect of tDCS stimulation of the AON to help induce enhanced accurate action anticipation as well as explore the associative effects of expertise, and frequency power changes. As hypothesized the results of this study indicate that tDCS can improve the results of a soccer occlusion task as shown in previous studies. Overall, expert gamers responded correctly more often. Furthermore, tDCS only improved correct responses for the expert group and not for the novice group. Additionally, tDCS only improved the correct scores for expert gamers in the early occlusion time condition compared to the novice gamers who showed no significant difference from tDCS.

We do not yet know why only expert participants and not novice participants improved due to tDCS intervention, especially as the tDCS ceiling effect is typically meant to be predominantly relevant to experts (Bullard et al., 2011; Tseng et al., 2012). One consideration may be that a certain level of mental representations are needed to be able to determine slight amounts of information to allow for improved anticipatory functioning as the gaming environment may be domain specific enough to translate some of the anticipatory functions and strategies from video gaming to a soccer simulation task.

Additionally, Bullard et al. (2011) points out that tDCS is considered more effective in improving learning when stimulated early in training, perhaps because neither of these groups were considered experts in the soccer task, the video game experts were more adept at learning new tasks within the familiarity of the gaming environment. The reason that this may not have an observed ceiling effect experienced with tDCS is because these skills may be more domain general that the domain specificity of gaming to the soccer task may be different enough that there is still room for improvement. Furthermore, this improvement may not translate over to results in improved scores for novice participants because novices have been shown to rely heavily on prefrontal regions to problem solve their way to a solution. However, due to cathodal stimulation inhibiting prefrontal regions this may have impeded the principal function that novices rely on and thus resulted in lower performance due to no other, more well-developed strategies, left to rely on.

Additionally, as expected, results showed that there was no difference between novice and experts for the easier condition of later occlusions. Jackson et al. (2006) considered that because the task at these later occlusions was merely determining change drawn from general skills relating to perception of biological motion and thus the novice group would have accrued a similar amount of experience based on normal daily activities. This may then speak to the novice ceiling effects compared to the expert gamers as they both may have a similar baseline of domain specific expertise. Therefore, there may have been a different engagement level between the two groups, with expert gamers more enthusiastic about the task and therefore more inclined to be more attentive and involved in the task.

The main aim for the frequency data was to compare the ERSP for correct predictions for sham versus active stimulation for expert video gamers as this was the only group that showed a behavioral improvement in successful anticipation scores. In particular, this research explored the behaviour of theta activity as an index of activity generated during anticipatory actions after right parietal anodal and left prefrontal cathodal stimulation. The main results from the theta ERSP was a large strong posterior response that lasted throughout the video clip and then continued after the occlusion. Additionally, a bilateral prefrontal theta response appeared 80ms prior to the occlusion and then after the occlusion moved primarily to a right frontal power increase compared to the sham condition.

Theta oscillations have been shown to promote top-down control over attention functioning afforded by strong interactions between the frontal, parietal and sensory areas (Cooper et al., 2017). The theta frontoparietal network has been shown to form a brain network that facilitates stimulus processing, integration and categorization of information (Hunter et al., 2018) Evidence from the literature has shown a posterior theta power increase related to visual working memory intensity, which is considered to provide better integration between top-down and bottom-up processes (Paul Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). Furthermore, parietal theta has been shown to improve recruitment efficiency of attentional resources to improve working memory (Hunter et al., 2018). Additionally, evidence has shown frontal theta activity as implementing top-down mechanisms over endogenous attention selection (Alekseichuk, Turi, de Lara, Antal, & Paulus, 2016). This was supported by Gredin, Broadbent, Findon, Williams, and Bishop (2018) who showed during a soccer occlusion task that frontal theta was related to an increased cognitive demand during anticipation tasks when analyzing contextual information.

Additionally, an unexpected bilateral frontal high gamma response was present prior and after the occlusion point. Interestingly, theta oscillations have been shown to modulate timing of spatial attention along the frontoparietal network through synchronizing with frontal gamma oscillations, resulting in improved visual attention and enhanced performance (Fiebelkorn, Pinsk, & Kastner, 2018). Frontal gamma band activity has been found to modulate visual working memory tasks such as target detection (Herrmann, Mecklinger, & Pfeifer, 1999) and internal representations of an object (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1997). Tallon-Baudry, Bertrand, Peronnet, and Pernier (1998) also showed when an object representation is actively held in short-term memory, sustained bilateral frontal gamma band activity is present throughout the delay of a delayed-matching-to-sample task. Gamma band modulation has been demonstrated by Wilson, McDermott, Mills, Coolidge, and Heinrichs-Graham (2017) to show frontal cathodal tDCS increases frontal gamma activity that is considered involved in visual attention. As the current study presented a continued gamma response after the occlusion, it is believed that the early period reflects a comparative visual working memory component of top-down (memory) and bottom-up (sensory) processes, while the later period reflects the integration and utilization of these comparisons (Herrmann, Munk, & Engel, 2004).

Finally, an additional increased bilateral posterior delta response was also present for the entire period before and after the occlusion. It has been reported that increased delta has been associated with improved learning rates (Maclin et al., 2011). Mathewson et al. (2012) tested learning rates during a videogame task and found that improved performance and learning speeds was associated with an increased bilateral posterior delta ERSP. Furthermore, Ardolino, Bossi, Barbieri, and Priori (2005) showed the ability for cathodal tDCS to modulate increased delta power, which may be indicative of why the tDCS group was able to improve throughout the testing period compared to the sham group.

Limitations

There are several important limitations to consider when interpreting the results of this current study. First, we did not test how adept people were at the soccer goalie task. While it is unlikely that the novice population had a higher level of soccer expertise compared to the expert gamer group, this would have helped reduce potential confounding effects. Additionally, when considering additional behavioral measures, it would have been informative to test the enjoyment of the task and hence the level of the participants' involvement in order to better understand the level of attention. Furthermore, the difficulty of finding female gamers that meet the criteria of the expert group meant that there was a gender bias in the expert group which makes it more difficult to relate these findings broadly as it is not truly representative of the larger population.

Another limitation was a lack of power in the current design due to a small sample size. No effect was found for the tDCS on novice expertise interactions, compared to the improvement for expert gamers despite the expected ceiling effects of tDCS on expert performers. This unexpected result may be due to the small sample size not supporting tDCS randomization within the matched groups. However due to the consistency in the novice group results it could be considered that the expert video gamer group was more easily able to adapt to new games due to domain general expertise, whereas the mix of an unfamiliar laboratory environment as well as learning a new game paradigm may have resulted as too overwhelming or distracting for the tDCS to have an effect on novices.

We found Brainstorm also had certain limitations in its analysis capabilities including the lack of statistical versatility and capability of managing more than 2 conditions and making use of the data for export. Additionally, the prolonged frequency responses found in the ERSP results could be a kindling effect bleeding across the epoch. Whilst artifact removal both offline and online was performed, this effect could be considered due to a static effect of tDCS but as the expert's EEG mirrors the behavioral improvement of their performance this outcome may also be a marker for how an expert's brain continues to modulate the prolonged effects of tDCS.

While this study's result could represent a performance enhancement shown in healthy neurotypical participants, it would be worthwhile to test the additive effect of tDCS on people that are experts and novice in the actual task e.g. soccer goalie. However, It has been argued that domain-general motor effects for action observation may not have to solely rely on domain-specific contributions (Press & Cook, 2015). Wimshurst et al. (2016) demonstrated partial support for domain-general expertise utilizing a hockey/ badminton occlusion task in which greater activation was seen in the parietal region, identified as critical to the AON, which was also the area stimulated in this study. Therefore, the predictive enhancement from the tDCS described in this study for expert gamers regardless of no soccer goalie expertise may be due to a domain-general benefit that could be explored in further studies on the application of tDCS in other clinical and professional populations.

Conclusions and future directions

To the authors' knowledge, this is the first published work to objectively examine the effect of tDCS on the AON resulting in successful anticipation effects while observing the relevant spectral power changes. The current study found an improvement from cathodal left frontal/ right anodal parietal tDCS in domain-general anticipatory predictions for expert gamers using a soccer goalie occlusion task, thereby suggesting a possible modification to the functioning of the AON. Furthermore, theta activity changes to the bilateral frontal parietal network and bilateral frontal gamma revealed a pattern of results consistent with the role of the AON. Furthermore, a left frontal delta and bilateral parietal response possibly provided an insight into a learning mechanism of the predictive task. Advancements in this field may potentially guide future research toward more effective neurocognitive training techniques that enhance a person's visual predictive capabilities that can be transferred to various aspects of clinical or professional applications.

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Chapter 7: A Transcranial Stimulation Intervention to Support Flow State Induction.

7.1 Publication 5: Rationale

This paper furthers the results from part 2 of the thesis looking at the role of tDCS in exploring the neurocognition of flow states by investigating the assistive role tDCS has in modulating the intensity of flow states for both recreational and occupational gamers during video game tasks. The research results focus primarily on performance accuracy as it has been shown to be a good indicator for modulatory enhancement of neurostimulation as well as helpful in determining the underlying role of neurocomponentry and its influence on cognitive functioning.

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7.2 Publication 5: A transcranial stimulation intervention to support flow state induction

7.2.1 Abstract

Background: Flow states are considered a positive, subjective experience during an optimal balance between skills and task demands. Previously, experimentally induced flow experiences have relied solely on adaptive tasks.

Objective: To investigate whether cathodal transcranial direct current stimulation (tDCS) over the left dorsolateral prefrontal cortex (DLPFC) area and anodal tDCS over the right parietal cortex area during video game play will promote an increased experience of flow states.

Methods: Two studies had participants play Tetris or first-person shooter (FPS) video games while receiving either real tDCS or sham stimulation. Tetris recruited 21 untrained players who infrequently played video games while the 11 FPS participants played FPS frequently. Flow experience was assessed before and after stimulation.

Results: Compared to sham stimulation, real stimulation increased flow experience for both untrained Tetris and trained FPS players. Improved performance effects were only seen with untrained groups.

Conclusion: Cathodal and anodal tDCS over the left DLPFC and right parietal areas, respectively may encourage flow experiences in complex real-life motor tasks that occur during sports, games, and everyday life.

7.2.2 Introduction

Flow, or optimal experience is a “holistic response” which results from a harmony found between all the states of consciousness and the individuals’ skills matching their goals (Csikszentmihalyi, 1990). According to Csikszentmihalyi’s (1990, 1997) flow theory, the flow state relates to the skill set perceived to be possessed by the individual relative to the perceived challenges of the activity. Challenges can be considered as “opportunities for action” thus flow is produced by any situation that requires skill (Csikszentmihalyi & Nakamura, 1999; Nakamura & Csikszentmihalyi, 2014). One of the leading neurocognitive theoretical models of flow purported by Dietrich (2004) denotes a state of transient hypofrontality, which enlists the full support of the implicit system to execute a task at optimal output (maximum skill/ maximum efficiency) while the majority of the online executive function of the prefrontal cortices are inhibited (Dietrich, 2004; 2006). Implicit memory has been identified as a key functional region in flow states as it reduces verbal-analytical involvement in motor control by encouraging limited dependence on working memory (Liao & Masters, 2002; Masters, 1992; Maxwell et al., 2001) enabling performance with higher neural efficiency than explicit motor tasks relying on working memory (Zhu et al., 2011). Whereas the automaticity reached in implicit memory are fast, effortless and free from distraction (Shiffrin & Schneider, 1977).

Specifically, the left dorsolateral prefrontal cortex (DLPFC) has been shown to modulate working memory (Barbey et al., 2013). Sharing Brodmann’s area 8 (BA8) and close proximity to the frontal left is the medial prefrontal cortex (MPFC) which has been associated with self-monitoring and reflective processing employed during explicit processes which limit the efficiency of the system (Gusnard, et al., 2001; Northoff et al., 2006; Shiffrin & Schneider, 1977; Yarrow, 2009). More recently, Ulrich et al. (2014) identified certain neural underpinnings that help explain part of the flow paradigm, in particular, a decrease in frontal activity around the MPFC.

Furthermore, the flow system is proposed to be a reflexive system guided by the preceding input (Dietrich, 2003). Therefore, it is believed that a basic level of skill acquisition is needed to have a flow experience, as the implicit system requires a series of learnt specialized and independent response patterns to output (Csikszentmihalyi & Csikszentmihalyi, 1988). These automated stimulus response procedures are believed to require many hours of highly dedicated practice. Learning of automated responses takes time because of the limited ability of the explicit working memory to transfer specialized and reflexive response patterns to the implicit system due to capacity restrictions (Dietrich, 2004; Mishkin et al., 1984). Experts are expected to have more automaticity available as the implicit system requires a series of specialized and independent response patterns to output, free from buffering other properties of the information in a higher order representation (Masters, 1992; Ohlsson, 2012). Flow is considered to increase in intensity on the continuum of experiential quality of the activity as the participant learns to utilize more of their dedicated facilities required for the task (Csikszentmihalyi & Csikszentmihalyi, 1988).

It has been shown that the brain makes use of an internal model which provides a sensorimotor representation of oneself with the world around (Jordan, 1996). Forward and inverse models can be utilized to explain the role of implicit processing by identifying the role of the network connecting the cerebellum, parietal and frontal regions to explain this control of high level processes such as decision making (Ito, 2008). These models consider that the prefrontal regions construct the mental model, but this mental model, used to explain and anticipate reality, exists in the parietal regions (Penfield & Perot, 1963), enabling the prefrontal region to be bypassed (Atherton et al., 2003; Chen et al., 2003). In one of the few neuroimaging studies on flow, an increase in activation was shown in the parietal regions as well as a decrease in prefrontal activity during a math task (Ulrich et al., 2014). Additionally, it has been shown that implicit bottom-up visual attention receives greater control from the parietal regions whereas top down control of more explicit processes are related to the frontal regions (Li et al., 2010). Furthermore, a long-range circuit has been found between these two regions that appears anatomically connected to guide choices toward movement goals (Pesaran et al., 2008; Sasaki et al., 1976).

To further test flow states and how it emerges, and possibly induced, is essential to better understand the flow state in practice. Transcranial direct current stimulation (tDCS) is a noninvasive brain stimulation technique that alters cortical excitability and activity in a polarity-dependent way. Anodal stimulation increases excitability (Liebetanz et al., 2002), whereas cathodal decreases it (Nitsche & Paulus, 2001). Stimulation for a few minutes has been shown to induce plastic alterations of cortical excitability and more specifically has shown to influence cognitive functions such as working memory by stimulating the left DLPFC (Chrysikou et al., 2013; Fregni et al., 2005; Zhu et al., 2015). Cathodal DLPFC tDCS has been shown to improve implicit learning outcomes for high-level motor tasks such as golf putting (Zhu et al., 2015) and cognitive flexibility (Chrysikou et al., 2013). Furthermore, it has been shown that tDCS has helped improve learning outcomes for implicit motor tasks, in which right parietal anodal stimulation resulted in greater neural efficiency through an improved task learning performance (Clark et al., 2012), as well as mental activities such as numerical competence (Cohen et al., 2010), network connectivity (Hunter et al., 2015) object detection during visual search (Bolognini et al., 2010; Clark et al., 2012; Tseng et al., 2012), spatial attention (Roy et al., 2015) and nonverbal material (Manuel & Schnider, 2016). Additionally, tDCS influence on parietal regions has shown a balance between the working memory capacity (skill) and the working memory task (Jones & Berryhill, 2012). More recently, (Ulrich et al., 2018) used anodal tDCS over Fpz to stimulate the medial prefrontal cortex (MPFC) and found higher flow experiences for people experiencing low flow. Therefore, tDCS learning enhancement could increase the level of visual attention skill in order that the participant could reach the skill challenge balance (Clark et al., 2012) and limit the role of the prefrontal monitoring in order to allow for greater movement into flow states (Zhu et al., 2015).

While flow states require a certain level of previous skill to be automatized into their implicit memory, tDCS has been shown to result in ceiling effects for experts compared to novice performers (Bullard et al., 2011; Furuyaet al., 2014; Rosen et al., 2016; Tseng et al., 2012). Therefore, two groups of trained and untrained video gamers were selected for the study to explore the contrasting effects of the required skill acquisition and expertise to move into flow states with tDCS ceiling effects of expertise. The Tetris game paradigm has proved easy to quantify performance and level of difficulty in both flow (Harmat et al., 2015; Keller & Bless, 2008; Keller et al., 2011) and tDCS studies (Spiegel, 2013). First person perspective video games have also shown to operationalize a good balance of skill and challenge with immersive experiences for both flow (Kivikangas, 2006; Klasen et al., 2011; Nacke & C. Lindley, 2008; Nacke & Lindley, 2008; Nacke & Lindley, 2010; Nacke et al., 2010) and tDCS studies (Bullard et al., 2011; Clark et al., 2012; Coffman et al., 2012; Falcone & Parasuraman, 2012). Therefore, both experimental paradigms were used to determine the mediating role tDCS will have in supporting the induction of flow states.

The focus of this study was to observe the inductive role of tDCS on flow states using 2 different paradigms. It was hypothesized that right parietal anodal tDCS and cathodal tDCS of the left prefrontal area would result in a shift in the subjective experience towards higher intensity experiences of flow states for both trained and untrained users of video games.

7.2.3 Material & Methods

Participants

Two experiments were ethically approved to study the effects of tDCS on flow states during video game play. All participants were recruited by word of mouth or from advertisements in game forums. Experiment 1 inclusion requirement was trained gamers played 1st person shooter videogames (FPS) on average several times a week. Eleven right-handed males (M = 29 years, SD = 7.15) played a FPS across two sessions within a week using randomized active and sham tDCS conditions.

Experiment 2 inclusion requirement was untrained gamers who on average played videogames once a month or less. Twenty-three participants were originally tested but two were corrupted due to their being initial pilot tests, therefore only 21 right-handed participants were tested; 11 females (M = 30.18 years, SD = 6.14) and 10 males (M = 31.8 years, SD = 3.61), played TETRIS® (Tetris Holding). Tetris was used for the untrained group as it is an easy game to learn and all participants were familiar with how to play it. Participants were randomly assigned between active and sham conditions.

Inter-Game Flow Questionnaire

At the end of each trial, participants were asked to retroactively assess their experience from their recent game trial and respond to a Flow State Scale (Jackson & Marsh, 1996) with two additional core questions of the flow state: “Everything Clicked” and “I was ‘in the zone’”.

Game play

In Experiment 1, participants were given the choice to play two different FPS games: “Counter Strike: Global Offensive” (Valve) or “Battlefield 4” (EA). Both games had the same settings of competing against live online players, most kills wins and played only in a single map environment. Due to different map, weapon and control settings, two games were used to allow players to participate in game the FPS game they felt most proficient in to give them the best chance to enter into flow.

In Experiments 2, three versions of TETRIS were used: slow (bored), adaptive (flow) and fast (anxious). The slow round was set to a speed of 2 and the drop button was disabled, forcing the person to sit around and wait for the piece to reach the bottom of the screen. The anxious round started at speed level 8 and would go up once a person made 5 lines. The adaptive condition started at 4 and went up in score if the player made 5 lines in 20 moves, but it would slow a level down if they had not met this criterion.

Stimulation

tDCS stimulation was applied using a NeuroConn DC-Stimulator (NeuroConn GmbH) machine with a montage of left prefrontal cathode and right parietal anode. tDCS was administered via two 5cm × 5cm electrodes covered with saline-soaked sponges. The stimulation site was determined by means of the 10/20 system, in which the cathode and anode were positioned over the F3 area and P6 area, respectively. Whilst tDCS excitability changes have been shown to last up to 60 min (Nitsche & Paulus, 2001), results have shown performance effects dwindle after 30 min of stimulation (Iyer et al., 2005). Therefore, stimulation condition was set for 20 minutes (including 10 seconds ramp-up and 10 seconds ramp-down time) at 2mA while sham condition also lasted 20 minutes but was set for 30 secs of stimulation at 1mA. Participants are shown typically unable to determine whether receiving real or sham stimulation (Gandiga et al., 2006).

Procedure

In Experiment 1, participants were told they were receiving tDCS stimulation over two separate sessions. In the first session, participants chose their FPS game and entered an online game room with 16 or more online players. The games' objective is to stop the other team therefore game scores were based on number of kills. Participants played a warmup round of free play without testing for about 20 mins while the experiment set-up occurred. Participants would then be informed that testing would begin. A trial would last until the participant lasted longer than 3 minutes and completed two kills in a row without dying. They then would be notified the trial had finished with a flashing light controlled by the researcher to fill out the Inter-Game Flow Questionnaire. The participant would press a button to acknowledge the light flash before answering the questionnaire.

The participant was randomly assigned a stimulation or sham condition which lasted 20 minutes of either 2mA for the active stimulation condition or 30 seconds of 1mA over the 20-minute period for sham condition. Participants would continue to play during that time without testing. Participants would then begin another testing session after stimulation following the previous testing procedure. Experiment 1 participants would return a week later and participate again with the same experimental protocol but receiving the opposite stimulation condition.

In Experiment 2, participants played a 15-minute warm up of the balanced condition prior to testing. Then the participants would be informed about a change in the gaming condition and they would complete two trials of the slow, fast and then adaptive TETRIS games for approximately three minutes. The researcher would then request they complete the Inter-Game Flow Questionnaire after each trial. The participant was randomly assigned a stimulation or sham condition which lasted 20 minutes of either 2mA for the active stimulation condition or 30 seconds of 1mA over the 20-minute period for sham condition. Participants would continue to play the adaptive condition during that time, and complete subsequent Inter-Game Flow Questionnaires. Participants would then begin another testing session after stimulation but only complete the adaptive and fast conditions.

Statistical Analysis

The research explored different hypotheses around performance ceilings as well as flow induction for the different training level of the groups to reduce learning effects and therefore enlisted different group design in the analysis.

Experiment 1

A repeated measures analysis of variance (ANOVA) was used to assess the significant main effect of the dependent variable, perceived state of flow score, during the first-person video game before and after the two trials (tDCS and sham).

Experiment 2

A mixed ANOVA was used to determine a significant main effect of the dependent variable, perceived state of flow score, during the events associated with each of the trials and games; e.g. this was compared to lines completed in TETRIS during different conditions. Similarly, a mixed ANOVA was used to determine a significant main interaction effect for tDCS stimulation with each of the trials and games.

7.2.4 Results

No participant reported experiencing adverse effects during or after tDCS. A slight itching sensation during approximately the first 30 seconds of stimulation was reported. The sham condition reported the same initial itching sensation, and when explicitly asked, believed to have undergone real stimulation.

An overall positive effect was observed for all participants from both experiments, in which participants from both experiments resulted in a significantly higher experience of flow states after tDCS compared to sham or control conditions. Experiment 1 hypothesized specifically that tDCS would modulate the experience of flow states for trained players of first-person shooter videogames. A repeated measures ANOVA determined a significant main effect of ($F[1, 54]=5.82$, $p < 0.02$, $\eta p^2 = 0.10$), see Figure 7.1. As hypothesized, simple main effects revealed that participants rated higher experiences of flow states after tDCS stimulation on average by ($M = 0.37$, $p < 0.001$, $\eta p^2 = 0.24$) compared to sham which increased non-significantly on average by $M = 0.08$.

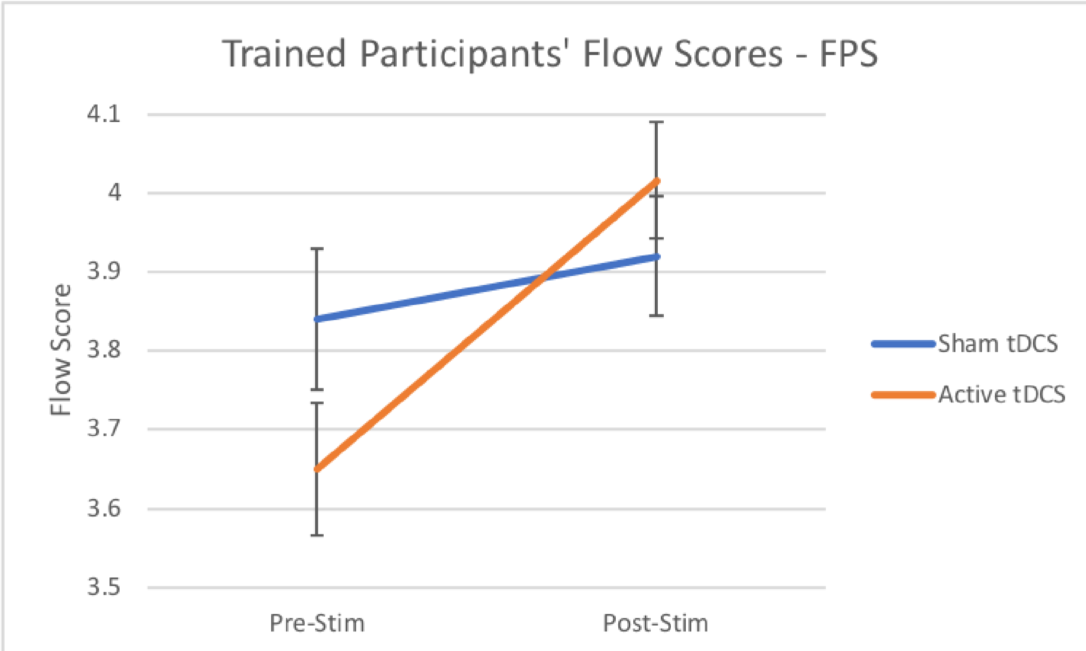

Figure 7.1: Flow scores from trained participants after Active Stimulation and Sham Stimulation. Bars – Standard Error

Additionally, there were non-significant effects for main effects of kill performance ($F[1,54]=0.214$, $p = 0.645$), see Figure 7.2, with greater performance improvements after tDCS on average by $M = .45$ compared to sham which reduced on average by $M = -0.2$.

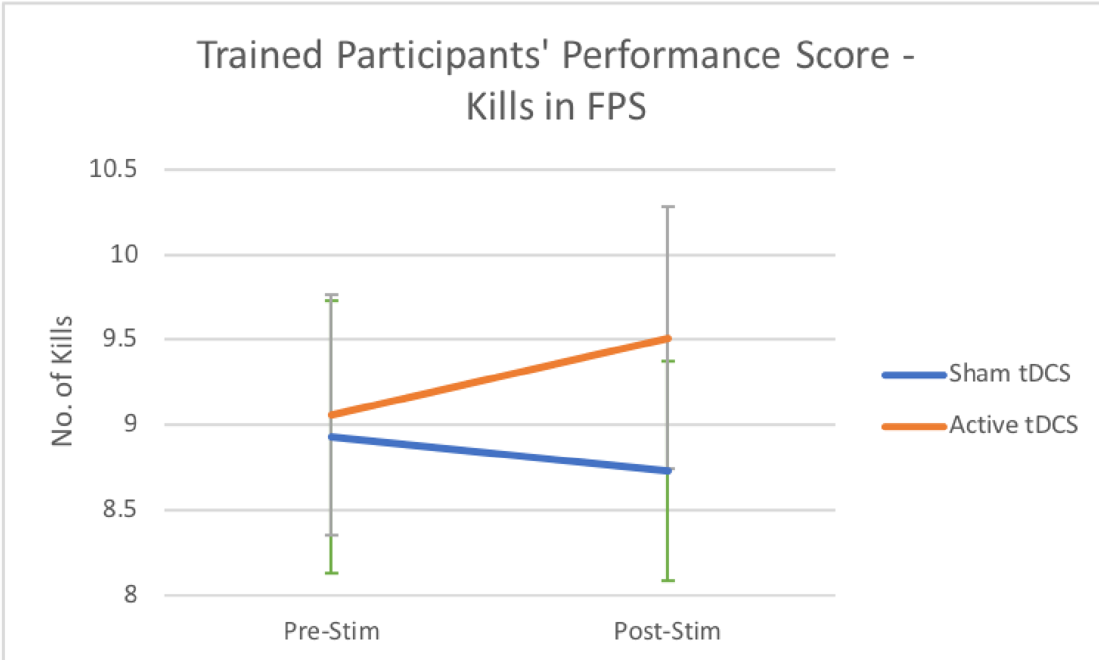

Figure 7.2: Number of kills performance scores from trained participants after Active Stimulation and Sham Stimulation. Bars – Standard Error

Experiment 2 also resulted in the expected modulation pattern of flow states for untrained players of the puzzle game TETRIS. A mixed ANOVA was used to determine a significant main interaction effect for tDCS stimulation ($F[1,48]=7.24$, $p < 0.01$, $\eta p^2 = 0.13$); see Figure 7.3. As hypothesized, planned simple main effects revealed participants in the flow condition rated higher experiences of flow states after tDCS stimulation on average by $M = 0.27$ ($p < 0.02$, $\eta p^2 = 0.22$) compared to sham which reduced non-significantly by $M = -0.13$. While there was no main effect for the interaction of tDCS over time for the anxious condition, a significant effect showed higher flow states after tDCS stimulation by $M = 0.27$ ($p < 0.05$, $\eta p^2 = 0.2$) compared to a non-significant effect for sham that increased flow scores on average by $M = 0.17$. Note that tDCS was not tested in the boredom condition.

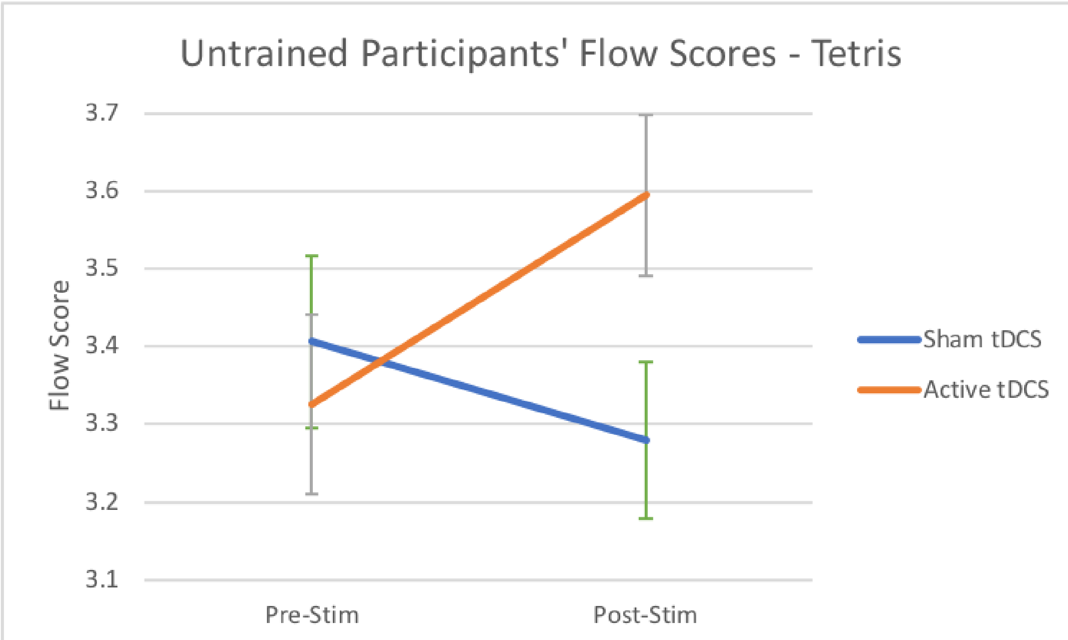

Figure 7.3: Flow scores from untrained participants playing TETRIS after Active Stimulation and Sham Stimulation. Bars – Standard Error

Additionally, as expected there was a significant main interaction effect for performance in TETRIS based on number of completed lines $F[1,48]=7.41$, ($p < 0.01$, $\eta p^2 = 0.13$); see Figure 7.4, with greater line completion performance after tDCS on average by $M = 3.54$ ($p < 0.001$, $\eta p^2 = 0.4$), compared to a non-significant effect for sham that increased line completion by $M = 0.31$.

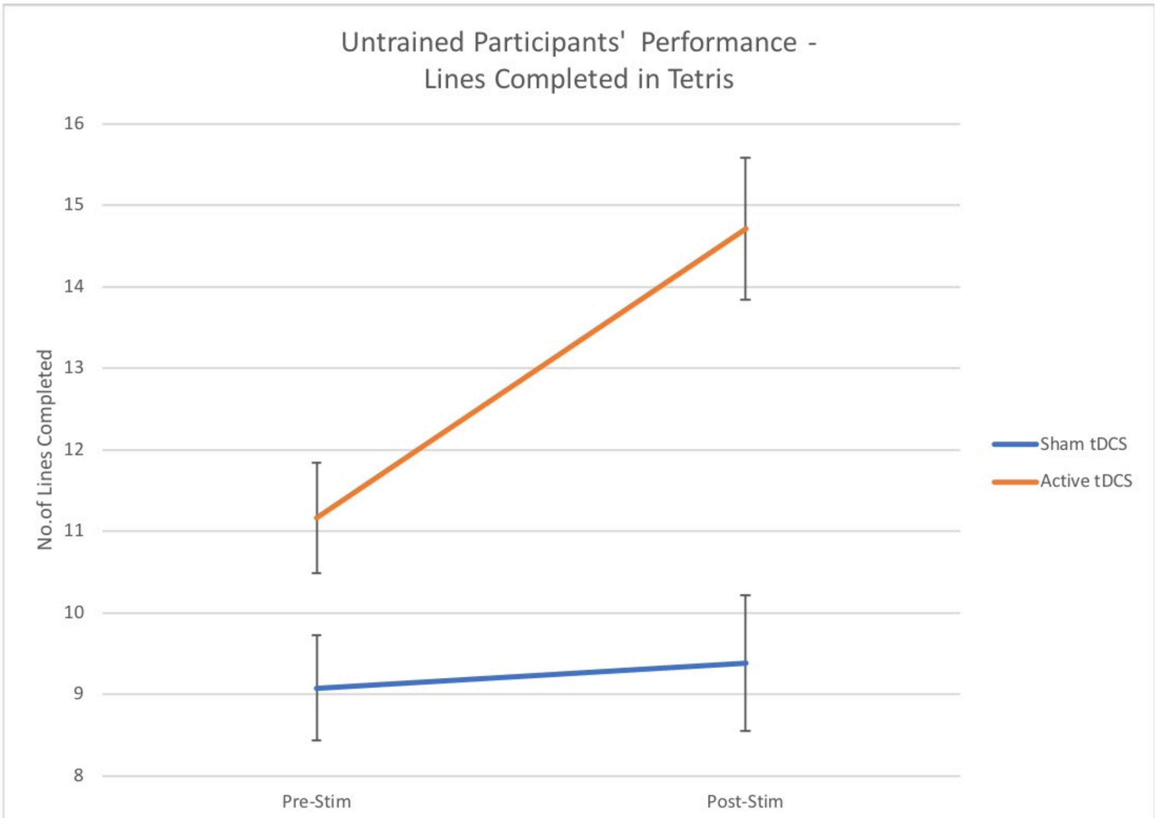

Figure 7.4: Number of completed lines - performance scores from untrained participants after Active Stimulation and Sham Stimulation. Bars – Standard Error

7.2.5 Discussion

As hypothesized, the results of this study indicate that tDCS can modulate an induction into flow states for video game players using a montage of prefrontal left cathode and right parietal anode. Additionally, as expected the trained FPS players performance was not improved by tDCS while the untrained TETRIS players improved due to tDCS stimulation compared to sham. While the results across both trained and untrained players of video games presented higher flow states after tDCS, the authors did find this interesting because it was unknown where the performance ceiling effect might also affect the experienced intensity of flow states. While tDCS ceilings effects were present in the performance results of this study, which has been shown previously to apply to expert compared to novice performers (Bullard et al., 2011), studies have typically observed this from the perspective of motor skill tasks and not for psychological states. Perhaps psychological states may not be limited in the realm of performance by tDCS, i.e. tDCS studies have been shown to improve mood (Nitsche et al., 2009) and maybe further worth exploring the difference in limits tDCS modulation has for psychological states compared to motor skills. Another reason for the lack of ceiling effect may be that the high frequency of game play in the trained versus the untrained group was not high enough to denote expertise and thus diminish the modulating effects of tDCS on flow states.

Whilst, to the authors knowledge, there has only been one prior research paper published on tDCS for flow states, which used a different montage of anodal stimulation over Fpz, the findings in this study could therefore be considered foreshadowed by previous papers documenting effects of tDCS in learning and working memory. The current findings align with previous research indicating that cathodal left prefrontal tDCS stimulation, as shown by Zhu et al. (2015), results in the reliance of improved implicit motor learning which could be considered to increase the modulation of the intensity of the flow experience as more resources are freed up for experiential processing (Dietrich, 2003). Inhibiting DLPFC has been shown to increase motor learning by disrupting the explicit motor system (Galea, Albert, Ditye, & Miall, 2010), as well as a dynamic balance with resources between explicit and implicit systems (Eichenbaum & Cohen, 2004; Kantak et al., 2012). The current study aimed to take advantage of this disruption of explicit executive functions to enhance the role of implicit processing and hence enable easier movement into elevated intensity of flow states. Furthermore, Zhu et al. (2015) reported a reduction in verbal working memory after the application of left prefrontal cathodal tDCS which Dietrich (2003) considers a requirement of his hypofrontality hypothesis to describe flow due to the reduction of high-level buffering and maintenance.

Furthermore, the current findings also align with previous right anodal parietal research indicated in Clark et al. (2012) which resulted in a positive learning effects in visual attention, thereby possibly reducing the amount of resources required to dedicate to the task to facilitate flow through implicit systems. Furthermore, the frontoparietal attention network has been shown as a brain network relevant to attention activation during target detection tasks (Posner & Petersen, 1990). A review by Andersen and Cui (2009) indicated the role that the posterior parietal cortices (PPC) plays in the frontal parietal network through sensorimotor transformations including planning, decision making, forward model estimation and attentional faculties. Additionally, the tDCS has been shown to influence parietal regions based on a balance between the working memory capacity (skill) and the working memory task (Jones & Berryhill, 2012) which appears quite similar to the principle antecedents of flow states (Csikszentmihalyi & Csikszentmihalyi, 1988). In this study, we suspect that as attentional resources continue to increase during visual search elements of a task, such as video games, it may lead to a greater probability of noticing target objects, enhanced encoding of the location of the target object within the image and, therefore, greater accuracy and less buffering. This reduction in processing requirement could possibly open up the processing capacity to increase the perception of skill and thereby result in higher flow states ratings.

Dietrich (2004) originally considers flow states a reflexive system however from these results a new understanding maybe beginning to unfold as flow states may better be considered a predictive system that has developed and implemented through "forward and inverse models" which are considered neurological attempts at predicting the outcome of each action (Kawato, 1999). Ito (2008) describes the forward model through the prefrontal, temporal-parietal and cerebellar network, in which the prefrontal area as the "controller" creates and transmits command signals that modify activities encoded while the temporo-parietal areas are considered the "mental model" which converts a command into an output action. Parietal anodal stimulation appeared to increase within network connectivity between key elements of the forward and inverse models including the inferior and superior parietal along with the cerebellar intrinsic networks, key for enhanced learning outcomes (Hunter et al., 2015).

This forward model could help explain the modulatory impact of the tDCS in inducing flow states as the system becomes less reliant on the moderating effects of the prefrontal controller whilst encouraging the ability to output commands fed in from the cerebellar network. This freedom from higher order interference enables the action output of the temporal-parietal regions the ability to more easily implement the memory model. This smoother activation free from frontal modulation may have resulted in the experience of less thinking and concern with the surroundings while the parietal excitation may have felt like an easier implementation of the memory models.

Additionally, the inverse model affords the prefrontal area to be bypassed and instead processing relies more heavily on the anterior cingulate cortex (ACC). The ACC has also been shown to be involved in flow states such as an EEG game study testing the difference between boredom, frustration and flow states (Nuñez et al., 2016). The ACC was determined as an actor in engaging the frontoparietal network as well as monitoring conflicts in the focus of attention (Walsh, Buonocore, Carter, & Mangun, 2011). However, more recently Ulrich et al. (2014) found in a similar three level (boredom, flow, overload) arithmetic fMRI study of flow that the ACC reduced in activity. Nonetheless, while more study is needed to ascertain its role in attentional focus and flow states, the pattern of decreased prefrontal activity and increased parietal activity reported in Ulrich et al. (2014), found flow state results that mirrored the frontoparietal network tDCS montage used in this study. It would be interesting to replicate this current study with a mirrored montage as the forward model appears to be supported by bilateral activation of the frontoparietal network.

Limitations

Whilst the results are indicative of a positive intervention of tDCS towards flow states, it would also be advantageous to consider the vast range of tDCS impacts. TDCS's effects have been shown as distributed rather than local (Keeser et al., 2011) and thus could impact unintended areas such that placing the prefrontal cathodal could influence multiple areas such as the DLPFC and the MPFC. Therefore, it may be worth considering using High Definition-tDCS in order to more accurately target locations associated with flow states in order to understand which areas specifically are responsible.

Furthermore, it is difficult to assess the full comparative impact of tDCS on flow and the ceiling effects between the trained and untrained players because the experimental design used a different methodology of a repeated experiment, alternating sham and tDCS for trained players while for untrained players they were only exposed one time to the experiment with a random allocation of tDCS or sham. This testing methodology in addition to testing between two different gaming paradigms or contributing factors to confounding the results. Therefore, for future testing it would be worth testing the role of tDCS ceiling effects on flow scores between trained and untrained players using the same experimental and gaming paradigm.

Additionally, it would be interesting to test different tDCS montages for modulating flow states. Flow states had been found in neuroimaging studies with both left and right parietal activation (Ulrich et al., 2014). Additionally, forward model neuroimaging studies have shown bilateral activation of parietal regions (Heinzel, Rimpel, Stelzel, & Rapp, 2017; Sokolowski, Fias, Mousa, & Ansari, 2017)

Conclusions

In the present study, we explored the subjective experiences of flow states for video gamers at different level of training after a tDCS intervention with a montage of a left prefrontal cathode and right parietal anode. Results revealed a subjective change towards higher intensity of flow experiences and an expected ceiling on task performance for trained and an improvement in task performance for untrained participants. With more research, tDCS could prove to be an effective tool to uncover more of the functional pathways involved in flow states and promote more positive subjective experiences for complex tasks including greater levels of immersion and enjoyment. By improving performance and states tDCS could assist people to become more diligent, motivated and effective in tasks for occupational and rehabilitative efforts.

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Chapter 8: Discussion

8.1 Introduction

Flow states are considered an altered state of consciousness in which people experience a series of psychological qualia that result in an experience of immersed effortless action based on the level of intensity of the experience. While certain psychological antecedents have been defined as relevant to help people access flow states, as well as neurocognitive studies beginning to shed light on the psychophysiological components underlying flow, much is still left both ill-defined and with a lack of empirical research. Therefore, the central aim of this thesis was to further explore different levels of expertise the cognitive strategies and neurocognitive models by using transcranial stimulating technologies. Additionally, we hoped to define a more comprehensive neurocognitive and cognitive predispositional model to better understand the functionality relevant to induce flow states.

In my thesis I investigated and expanded on the role of several neurocognitive models related to flow states that have been researched across a number of studies around the world and from a variety of academic disciplines including expertise, marketing, computer interface, athletics and general cognitive neuroscience. The restriction of this work was that the testing methodology was varied and ill-defined without taking the full gamut of up to date research into consideration and administering the test in environments more akin to scenarios that are pertinent to the person’s individual flow task. Furthermore, we also wanted to see if flow states could be initiated based on the state of current research in transcranial direct current stimulation (tDCS) in order that it would guide the application of this technology.

1. In conducting literature reviews on the current state of flow research (Chapter 1) as well as neurocognitive theories of flow states (Chapter 2), I was able to better determine a baseline for the current understanding of flow states as well as the differences and overlapping functionality to help determine a new role for the cerebellum when considering internal models.

To understand first the cognitive profile of flow states, I aimed to look at the role of personality dispositions in different professional settings.

2. In Chapter 5, I tested dispositional cognitive traits and the moderating role of mindfulness to determine if they help explain dispositional flow states and determined whether there was a different profile for recreational versus occupational tasks.

As flow states need to not only be understood at the cognitive level but also at the deeper neurocognitive functionality, I aimed to look at the influence of transcranial stimulation technology and its role in inducing flow states.

3. I next ran an EEG/ tDCS study in Chapter 6, using a temporal occlusion task in order to determine the neurocognitive impact tDCS has on improving performance in video games tasks.

4. In Chapter 7, I then ran a study to determine the impact tDCS has on helping to induce flow states based on the current neurocognitive research.

8.2 Main findings of the cognitive section of the study

1. The study showed support for key cognitive strategies people are predisposed to in order to better determine the role personality plays in facilitating flow states across different task settings

A multi-group structural equation model tested a mediation model which revealed that mindfulness significantly mediated the relationship of need for cognition and active coping on flow states in occupational settings and overall, but not in recreational settings. Whereas in recreational flow tasks, only active coping had a direct relationship in explain variance in flow states.

8.3 Implication for the cognitive section of the study

While there have been many cognitive studies addressing flow states, there has been far less comparing the personality differences that inform flow during occupational tasks compared to recreational tasks. The results of this study have provided some unique indications that flow, in different tasks throughout our lives, can require different arrays of personality traits to utilize in order to achieve flow in these different situations. From the study, however, we can see some shortcomings in the data and it would be advantageous to gain some greater insight on additional elements that may influence the results such as the level of skill a person may have in their recreational task as different levels of expertise have been shown to result in different coping styles. A study showed highly skilled athletes tended to rely more heavily on active task oriented coping styles than their less skilled counterparts (Gaudreau & Blondin, 2002). Future research in turn may want to explore the influence of different skill level to determine if this results in a change in frequency of achieving flow states as well as what other personality traits of low and high skilled people partaking in recreational activities may be predisposed to implement in order to achieve flow.

An additional component of this research may be to determine why a person chooses to make their flow task occupational or recreational. To ensure the intrinsic motivation of the task is maintained is it best for the individual to separate it from eternal rewards like financial incentives or social capital. Otherwise might a lack of self-confidence contribute to a person shying away from an occupational career with their flow task? These additional components and others may better help explain the different motivations people take into consideration when performing the different tasks in their lives in order to better help them understand how to get the most reward and growth out of the activities they choose to participate in their lives.

Due to the results of this study revealing different psychological approaches to flow based on whether the task is occupational and recreational, we can see that is important to further delineate consequential elements such as criticality of the task, achievement motives and importance. These elements would help determine occupational impacts such as the pressure of income in which the external reward of a person performing flow during occupation may also influence the implicit achievement motive in the sense that a fear of failure may exist in occupation as they have theirs and potentially their family's livelihood riding on their performance. Furthermore, exploring the constant nature of daily occupational performance compared to the more variable frequency of recreational flow tasks may prove relevant as Viljoen (2018) showed an significant association for the frequency of playing as full time musicians compared to the belief of part time musicians that the routine nature of daily performance would inhibit flow. Therefore, occupational flow may be governed more by an enduring career and motivated by the ability to sustain oneself while recreational flow is based more on the task at hand in that moment with less involvement of a motivation for the consequential impacts of future failures. These results support the current findings in this thesis and would be worthwhile to explore further.

8.4 Main findings of the neurocognitive section of the study

1. The current work expands and further defines key components of the two main neurocognitive models by identifying overlapping contributory functions of the basal ganglia. Additionally, the research pointed to a strong contribution of the cerebellum and the role of forward and inverse models to explain much of the qualia associated with flow states.

The study did a comprehensive review of all current flow studies pertaining to these two theories and built a model that worked to integrate elements described from both theories as well as the contributions and interconnections of both the cerebellum and the basal ganglia.

2. The soccer occlusion tDCS study revealed a significant performance improvement for expert gamers as well as frequency modulation at key topographies and spectral ranges.

The effect of tDCS on the temporal occlusion task resulted in increased accuracy of anticipated direction of the soccer sports task primarily in the more difficult early occlusion task. This resulted in primarily an activation of the frontoparietal regions in theta and delta frequency ranges which is indicative of increased top down attention and learning, respectively as well as a high gamma bilateral frontal response that that results in enhanced performance in visual attention

3. The results of this tDCS showed that stimulating the frontoparietal network can help promote flow states in both novice and experienced video gamers.

Whilst the performance ceiling effect was maintained for experts compared to novices both groups experienced an enhancement in state of flow after being exposed to frontoparietal tDCS stimulation and providing support to the transient hypofrontality hypothesis with cathodal inhibitory stimulation over the left DLPFC.

8.5 Implications of the neurocognitive section of the study

The main implication of tDCS is to not only determine if it can assist in induction of a particular state but also act as a probe to identify relevant functional neurocomponentry as well as to validate theoretical models presented in the literature.

In this body of work, tDCS was identified as providing a role in helping to help induce flow states. While this could prove useful as a way to help people attain greater levels of happiness as flow has been shown to be associated at all stages of life with positive moods and life satisfaction (Collins, Sarkisian, & Winner, 2009; Sahoo & Sahu, 2009). However, this this only focused on a particular montage of a left cathodal montage which is useful for testing the THH. Another tDCS study by Ulrich et al. (2018) also ran a tDCS study on flow using only a frontal central stimulation site and also was able to help support the THH.

To date though there has not be any transcranial stimulation study to test the network synchronization model. One way this may be achieved is through the use of transcranial alternating current stimulation (tACS) which works similarly to tDCS but the current alternates at a selected specific frequency related to functionally-relevant oscillatory brain potentials and resulting in a possible entrainment of neural networks at the stimulated frequency range (Antal & Paulus, 2013). TACS has been shown to modulate spectral frequencies and improve performance in multiple areas including spatial reasoning (Kasten & Herrmann, 2017), working memory (Jaušovec & Jaušovec, 2014) and fluid intelligence (Pahor & Jaušovec, 2014). Flow studies have shown synchronized neural groups through increased coherence triggered a stronger theta cortico-cortical communication between right temporal and premotor cortex in a table-tennis imaging task (Wolf et al., 2015). More recently, a study by Lang, Gan, Alrazi, and Monchi (2019) reported an enhancement to performance in a visual association task in which they applied theta tACS to the right temporal lobe compared to tDCS which showed no improvement.

With the introduction of the cerebellar internal models as possible neurocognitive model for flow states, cerebellar tDCS (tcDCS) could prove an effective way to test for the validity of this model. Recently, tcDCS was used to identify the cerebellum having a critical role in procedural learning in a visual attention study in which anodal tcDCS enhanced implicit learning as relating to the development of specific motor skills and cognitive activity which are relevant to the induction of flow states (Ferrucci et al., 2013). Additionally, several more tcDCS studies have been run to show enhancements in locomotor adaptation (Jayaram et al., 2012) and task specific facilitation of working memory and attention (Pope & Miall, 2012). Furthermore, tcDCS studies have begun to test internal models providing evidence of forward model modulation through cerebellar stimulation.

In considering this recent body of research a potential study to test the role of STF and tcDCS may be to utilize TETRIS testing paradigm used in Gold and Ciorciari (2019) in which participants are receive either a) the frontoparietal tDCS montage, b) a tACS application to the right temporal region and central premotor cortex or c) an anodal tcDCS to determine if these stimulations could better help induce flow states in comparison to each other.

Another project considered to be undertaken for this thesis, but due to time restrictions was not possible to implement, was an investigation into athlete's performance changes using neuro-modulation technology as an inductive method for flow states. Elite athletes would be recruited through P3.md high performance training institute to participate in this study. Participants would be taken through previously unlearned training techniques developed by P3 to identify their learning capacity. These participants would then complete two series of training exercises, in which they will be exposed either to a sham condition or a tDCS stimulation for 25 minutes before the repetition of the second session. Participants would be asked to fill out a flow state scale at intervals throughout the training sessions. This project was included with the ethics approval for the current study and agreements with P3.md an elite sports training facility (See Appendix 8).

Additionally, the action observer network (AON) has been shown to afford humans the ability to embody the intentions of another person's actions merely by observing them (Grafton, 2009). A more recent study by Avenanti, Paracampo, Annella, Tidoni, and Aglioti (2017) has shown that tDCS over the left frontal region can modulate the ability for a person to understand and anticipate these intentions. A meta-analysis showed this same region shares a crossover between action observation, imitation and the mirror neuron network (Caspers et al., 2010). An implication of this research could be added onto the athlete flow study by including both a domain-specific and domain-general mirror task prior to the athletic task for both sham/ tDCS condition in which the participant will watch a video of a domain-specific high level performance as well as a domain-general high level performance such as an unrelated sport and rate the experience of their intensity of flow following the video to determine the impact of tDCS on action observation as an avenue into accessing flow states.

8.6 Integration of findings and future considerations

When comparing occupational and recreational users of video games in Gold, J. Ciorciari, J. (2020a), a difference was found in the effect tDCS had on the accuracy of their performance in which tDCS only provided assistive benefits to the occupational players during a domain general task. Additionally, we saw a strong activation of the frontoparietal network of expert performers denoting concentration and immersion in the task. This immersion level has also been shown in flow states where Katahira (2018) also showed strong activation of frontal theta due to the level of cognitive control. This was further supported by Gold and Ciorciari (2019) whom also showed benefits only to occupational players after tDCS to the frontoparietal network but this time for a flow tasks. Therefore, future research may consider ascertaining the different neurocognitive pathways different cognitive strategies such as mindfulness and active coping may rely on. The stimulation of specific neurocognitive pathways may further support the induction of cognitive strategies or enhance its functionality.

In Gold, J. Ciorciari, J. Critchley, C.R. (2020), a difference was also found between recreational and occupational people in flow states in that occupational people relied more heavily on mindfulness while people achieving flow in recreational tasks more likely to utilize active coping strategies. One consideration to help explain these differences that we are seeing between occupational and recreational flow tasks is that occupational people tend to manage their task through the anticipatory strategies of mindfulness that afford them a high level of cognitive control compared to a more reactive approach of active coping strategies.

Another consideration to come out of the tDCS component of these studies is the role of the cerebellum takes after the prefrontal cortex has been inhibited. i.e. In Gold and Ciorciari (2020), the role of inverse models controlled from the cerebellum were discussed as a possible new model for the neurocognitive control of flow states and expertise. The model states that the executive control of the prefrontal areas is bypassed by the cerebellum to guide both cognitive and motor functions for the task at hand. In both Gold and Ciorciari (2019) and Gold and Ciorciari (2020a), cathodal tDCS was applied to the frontal left prefrontal cortices thereby inhibiting the executive functioning role of this area. This leads to the consideration that due to the reduced reliance on prefrontal cortices to guide actions, greater reliance may be placed on regions of the basal ganglia such as the striatum and in particular the cerebellum. Future neuroimaging research may therefore want to examine the activity and role of the cerebellum and basal ganglia after the prefrontal region has been inhibited from transcranial stimulation.

8.7 Limitations

The major limitation throughout the thesis are the small sample sizes. The results from the study on the cognitive outcomes (Chapter 5) should be interpreted with caution as they were drawn from a relatively small sample, which in the scope of my PhD was very difficult to accomplish and should be addressed in future research. This small sample size was also prevalent in the neurocognitive studies, yet these sample sizes were relatively not as small due to the nature of the research and the statistical tools available.

There is also the problematic issue of the generalizability of the data with the sampling age due to the experiment’s demographic consisting of primarily healthy, young educated individuals. Furthermore, the difficulty of finding female gamers that meet the criteria of the expert group meant that there was a gender bias in the expert group which makes it more difficult to relate these findings broadly as it is not truly representative of the larger population. This sample is further skewed when considering the expert video game players for experiment 1 is only male participants and while the novice Tetris video gamers for experiment 2 are more evenly spread across gender this data again needs to be considered for the generalizability of the application of these findings. It also further encourages the same experiment to be conducted in a comparably all-female sample to investigate sex-related commonalities and differences in the neural correlates of flow.

Another consideration for the different results in the cognitive strategies may have been obtained if flow tasks were grouped differently for analyses, for example, limiting the recreation task to something specific like video gaming. Furthermore, for both the tDCS as well as the cognitive strategies tasks while the level of expertise may be more easily understood when considering a professional, it is less clear, yet still as important, to understand the level of expertise a person has in their recreational task as this may inform what type of cognitive strategies a person may be more inclined to utilize during their flow task. From this we can see particular shortcomings in the data, and it would be advantageous to gain greater insight about additional elements that may influence these results such as the level of skill and expertise a person may have in their recreational flow task.

8.8 Academic contributions

Flow literature has shown inconsistent design methodologies in addressing both self-report and neuroscientific research due to how flow is conceptualized as well as what are considered the most important elements of flow to focus on. In addressing the existing body of research this thesis was able to collate, synthesize and discuss the relevant areas of research, utilizing modern measurement (such as EEG) and induction (e.g. tDCS) techniques to determine where key elements of flow function may be localized. This research will help the academic flow community to build on the research to better understand how flow works in the brain.

This thesis addressed both of the principle forms of flow research methodology with a single flow task as well as the 3-part boredom/ anxiety/ flow task using transcranial stimulation technology to show that both the methodologies appear to hold up as effective research designs for measuring flow states. Additionally, this further validates the Jackson and Eklund (2004) scale which conceptualizes autotelic personality trait as its own component in the flow scale. This intrinsic reward was particularly relevant to the contributions in Chapter 5 which explored the different cognitive components relevant to tasks that have inherently different motivations between and occupation and recreational tasks.

This thesis also provided a new cerebellar model for academics to consider as a way for understanding how flow states are facilitated in a way that affords a neuronal resource efficiency. This shared basal ganglia-cerebellar consideration may be open up considerations for performance-based fields such as expertise studies in general as well as the potential for the field of transcranial stimulation technologies on the cerebellum as a performance facilitator and neurocognitive probe. Furthermore, by providing insights into the role tDCS has in helping to facilitate psychological states, this study contributes not only to the understandings of transcranial stimulation as a way facilitating performance but also as a tool to probe and validate neurocognitive theories of underlying functioning. Academics can now begin to probe other functional areas of the brain considered to be relevant to flow states and other fields in performance enhancement as well as visual attention tasks. Furthermore, this may lead to further academic projects utilizing other transcranial stimulation technologies such as tACS, and TcDCS.

8.9 Applied contributions

From an applied perspective this research can help result a facilitation in performance improvement across many different areas in the modern workplace with countless distractions. Flow states have been shown to greatly improve productivity at work in both managerial as well as blue collar workers. In a 10-year study executives reported being 500% more productive in flow states (Cranston & Keller, 2013). Furthermore, in performance-based jobs such as sports professionals, improving performance by a single point can mean the difference between a bad game and a great day at work. Therefore, both the cognitive and neurocognitive findings from this study can make a useful contribution. Firstly, through testing key cognitive strategies such as the implementation of mindfulness programs to help facilitate the opportunity of people entering into flow states. Additionally, the application of transcranial stimulation technologies such as in gamified digital environments has also shown to show an improvement in flow and performance for people in occupational tasks. What is interesting about this contribution is that we saw that unlike people who participate in recreational tasks, people who participate in occupational tasks show not only a performance advantage and but also show this across a general-domain expertise rather than needing to stay within a specific domain. This could result in people improving their performance across different tasks within their field through the use of transcranial stimulation technologies.

Recreational performance is also important to consider as it has been shown that for people who are not executives, flow intensity is much higher as recreational tasks than occupational tasks (Csikszentmihalyi & LeFevre, 1989). Therefore, the application of interventions to help encourage flow during recreational tasks could be useful to help instill life satisfaction and enjoyment through the facilitation of flow states. The administering of active coping techniques could be helpful to consider include during coaching programs as a way for handling stress within the task in order to encourage onset of flow states as well as manage surrounding features of the activity that can impact flow such as recovery from injury. Furthermore, transcranial stimulating technology also showed itself to be helpful for recreational use in supporting flow state induction and while a ceiling performance effect was shown in Chapter 7, tDCS has also been shown to be useful in improving performance scores primarily for novices.

Consequently, the application of cognitive strategies and transcranial stimulation technologies have an opportunity to improve personal well-being and life satisfaction through the promotion of greater improvement and productivity in people's occupations as well as their pastimes. The research included in this thesis has shown what types of strategies can be effective to improve performance in different flow tasks and how to apply to them in regard to the application tDCS. This further provides an opportunity for neuroscientists and cognitive researchers to focus more efforts in applying their work to professional and recreational endeavors in order to gain more real world understanding of the impacts of their research. This research improves understanding of how the adoption of cognitive and neurocognitive research can be implemented into real life applications. Therefore, this research has significant implications in the selection of strategies adopted in the future design of effective coaching and managerial programs which as a result may increase their impact and potential to improve productivity and performance.

8.10 Research and publications impact

Publication 1: Peer reviewed paper (submitted)

- Invited to give presentation of research at McGill University, Montreal Canada

Publication 5: A Transcranial Stimulation Intervention to Support Flow State Induction

- Citations: 2
- Paper included in Frontiers for Neuroscience e-book: “Neuromodulation in Basic, Translational and Clinical Research in Psychiatry”
- In the last 12 months, this article has had more views than 84% of all Frontiers articles with 6,871 views.

8.11 Concluding remarks

There is an ongoing challenge to determine the neural correlates of flow states, in which researchers are drawn to implement the array of modern tools and techniques available to them in order to better discern the key neurological markers that can aid in better determining these elusive states to afford a greater understanding of optimal functioning. The current state of markers and measures are varied and for the most part underrepresented in the research or inconsistent from the theories and previous findings. It is important that more standardized testing is implemented in particular the measures and tasks in order to get more precise well validated and reliable findings especially as there are still multiple questions surrounding the validity of the numerous neurocognitive models of flow states still being explored.

This thesis drew attention to tDCS as a reliable tool to explore the neurological underpinnings of flow states as well as help its induction using a particular montage that provided further support for the hypofrontality hypothesis. This research also raised additional questions about the overlooked role of the cerebellum and the relevance of internal models in relation to initiating key facets of flow states. Furthermore, it explored the impact of tDCS in the context of flow inducing activities for both occupational experts as well as recreational novices.

Additionally, this research explored key personality traits that support the predisposition of flow by focusing on predisposed cognitive traits to find the importance of the mediating role of mindfulness. In particular these cognitive models were further explored in both occupational and recreational contexts to show that situational differences can result in different motivations which lead to a reliance on different cognitive predispositions in order to enter flow states.

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Appendices

Appendix 1: Joint authorship

SWINBURNE UNIVERSITY OF TECHNOLOGY

Swinburne Research

Authorship Indication Form

For HDR students

NOTE

This Authorship Indication form is a statement detailing the percentage of the contribution of each author in each published 'paper'. This form must be signed by each co-author and the Principal Supervisor. This form must be added to the publication of your final thesis as an appendix. Please fill out a separate form for each published paper to be included in your thesis.

DECLARATION

We hereby declare our contribution to the publication of the 'paper' entitled:

A review on the role of the neuroscience of flow states in the modern world

First Author

Name________________________ Signature:________

Percentage of contribution: 95 %   Date: 29/ 06 / 2020

Brief description of contribution to the 'paper' and your central responsibilities/role on project:

Collected the data and wrote the paper

Second Author

Name: Joseph Ciorciari   Signature:________

Percentage of contribution: 5 %   Date: 29/ 06 / 2020

Brief description of your contribution to the 'paper':

Helped review the paper and the concepts

Third Author

Name:________________________ Signature: ________

Percentage of contribution: ____%   Date: __/__/____

Brief description of your contribution to the 'paper':

Swinburne Research

Authorship Indication Form

For HDR students

NOTE

This Authorship Indication form is a statement detailing the percentage of the contribution of each author in each published 'paper'. This form must be signed by each co-author and the Principal Supervisor. This form must be added to the publication of your final thesis as an appendix. Please fill out a separate form for each published paper to be included in your thesis.

DECLARATION

We hereby declare our contribution to the publication of the 'paper' entitled:

A neurocognitive theory of flow states and the role of cerebellar internal models

First Author

Name: Joshua Gold Signature:

Percentage of contribution: 95 % Date: 29/06/2020

Brief description of contribution to the 'paper' and your central responsibilities/role on project:

Created and ran the experiment, computed the results and wrote the paper.

Second Author

Name: Joseph Ciorciari Signature:

Percentage of contribution: 5 % Date: 30/06/2020

Brief description of your contribution to the 'paper':

Helped review the paper and concepts

Third Author

Name:___ Signature: ___

Percentage of contribution: ___% Date: __/__/____

Brief description of your contribution to the 'paper':

SWINBURNE UNIVERSITY OF TECHNOLOGY

Swinburne Research

Authorship Indication Form

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NOTE

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DECLARATION

We hereby declare our contribution to the publication of the 'paper' entitled:

The mediating role of mindfulness in explaining individual differences in flow during recreation and work.

First Author

Name: Joshua Gold Signature:

Percentage of contribution: 85 % Date: 29/06/2020

Brief description of contribution to the 'paper' and your central responsibilities/role on project:

Created and ran the experiment, computed the results and wrote the paper.

Second Author

Name: Christine Critchley Signature:

Percentage of contribution: 10 % Date: __/__/____

Brief description of your contribution to the 'paper':

Developed the statistical model for the results section.

Third Author

Name: Joseph Ciorciari Signature:

Percentage of contribution: 5 % Date: __/__/____

Brief description of your contribution to the 'paper':

Helped review the paper

Swinburne Research

Authorship Indication Form

For HDR students

NOTE

This Authorship Indication form is a statement detailing the percentage of the contribution of each author in each published 'paper'. This form must be signed by each co-author and the Principal Supervisor. This form must be added to the publication of your final thesis as an appendix. Please fill out a separate form for each published paper to be included in your thesis.

DECLARATION

We hereby declare our contribution to the publication of the 'paper' entitled:

Impacts of transcranial direct current stimulation on the action observation network and sports anticipation task

First Author

Name Joshua Gold Signature:

Percentage of contribution: 95 % Date: 29 / 06 / 2020

Brief description of contribution to the 'paper' and your central responsibilities/role on project:

Created and ran the experiment, computed the results and wrote the paper.

Second Author

Name: Joseph Ciorciari Signature:

Percentage of contribution: 5 % Date: 30 / 06 / 2020

Brief description of your contribution to the 'paper':

Helped review the paper and concepts

Third Author

Name:__________ Signature: __________

Percentage of contribution: ____% Date: __ / __ / ____

Brief description of your contribution to the 'paper':

Swinburne Research

Authorship Indication Form

For HDR students

NOTE

This Authorship Indication form is a statement detailing the percentage of the contribution of each author in each published 'paper'. This form must be signed by each co-author and the Principal Supervisor. This form must be added to the publication of your final thesis as an appendix. Please fill out a separate form for each published paper to be included in your thesis.

DECLARATION

We hereby declare our contribution to the publication of the 'paper' entitled:

A transcranial stimulation intervention to support flow state induction

First Author

Name Joshua Gold Signature:

Percentage of contribution: 95 % Date: 29/ 06 / 2020

Brief description of contribution to the 'paper' and your central responsibilities/role on project:

Created and ran the experiment, computed the results and wrote the paper.

Second Author

Name: Joseph Ciorciari Signature:

Percentage of contribution: 5 % Date: 30 / 06 / 2020

Brief description of your contribution to the 'paper':

Helped review the paper and concepts

Third Author

Name: ______ Signature: ______

Percentage of contribution: ____% Date: __ / __ / ____

Brief description of your contribution to the 'paper':

Appendix 2: Reviewer's comments

Publication 2

Ref: BRCG_2019_349

Title: A neurocognitive model of flow states and the role of cerebellar internal models

Journal: Brain and Cognition

Dear Mr. Gold,

Thank you for submitting your manuscript to Brain and Cognition.

It has been difficult to find reviewers. I have, however, received one thorough and competent review. I have also read the manuscript for continuity and generally agree with the comments in the review.

Although the topic is of great interest, there were significant weaknesses that seriously constrain the import of the paper. I very much regret that we cannot consider the manuscript for publication.

Please refer to the comments listed at the end of this letter for details of why I reached this decision.

We appreciate your submitting your manuscript to this journal and for giving us the opportunity to consider your work.

Kind regards,

Henri Cohen, Ph.D.

Editor-in-Chief

Brain and Cognition

Comments from the editors and reviewers:

-**Reviewer 1**

- In this manuscript, the authors review the different models and concepts thought to underwrite flow states, i.e. a nearly effortless yet near-optimal state of performance on a challenging task accompanied by a somewhat reduced self-awareness. The authors discuss the two most prevalent models of transient hypofrontality and network synchronization, before introducing a hypothesis based on cerebro-striato-cerebellar adaptation of internal models. While the manuscript is timely and of interest, it is not very well written from grammatical, orthographic and logical points of view. The manuscript also lacks page numbers and, at least in the version accessible to the reviewers, a bibliography. Unfortunately, all of the above substantially hamper the quality of the manuscript and its value to a potential reader. Overall, the authors may wish to rephrase, shorten and/or separate their sentences, most of which are exhaustingly long.

1. The major concern: the authors introduce a potential role of the cerebellum in flow states and the other hypotheses in detail. As the models do not seem

mutually exclusive, the lack of an overarching view and integrative model combining these hypotheses seems puzzling and prevents the manuscript in its current form from providing a potentially compelling contribution to the field. It is odd that the authors also barely refer to the internal models in Discussion, Future Directions or Conclusion

These models are additive rather than mutually exclusive. This has now been clarified throughout the paper:

“While the shared findings of the THH and STF both appear to focus on mental economy and implicit processing alongside synchronized activation of the striatal reward system associated with intrinsic motivation, conflicting evidence also appears to present around differing results both supporting and contradicting hypofrontality as well as the importance of synchronous networks for flow to occur. Such discrepancies open up the possibility for new considerations that may speak to these similarities and discrepancies whilst explaining other key neural functions activated to further create a more comprehensive neurocognitive model of flow states.”

2. The authors' analysis and presentation of cerebellar processing appears rather superficial and needs substantial reconsideration, e.g.:

2.1 "Inhibitory signals refine behaviours...": this appears to be overly generalized and simplified

Clarified:

“Inhibitory signals from the cerebellar nuclei refine behaviors of cerebellar micro-complexes that store models of specific functions, via the input-output relationship of the olivary “error detection” system by comparing the current action with the existing internal model (Ito, 2006).”

2.2 the role of the cerebellum in decision making is still highly disputed –

Evidence referenced:

(Deverett, Koay, Oostland, & Wang, 2018; Ito, 2008).

2.3 "anatomical loops sent to all cortical sites" is again oversimplified (e.g. no loops with the occipital cortex)

This was taken from inverse model and validated with evidence. Further clarified:

“This cerebellar predictive processing relevant for motor, sensory and cognitive behaviour is mirrored by anatomical loops sent to all cortical sites, from the cerebellum’s dentate nucleus via the thalamus and in turn receives feedback via the pontine nuclei (Ramnani, 2006).”

2.4 "The visual cortex then modifies motor feedback" is unclear and should be substantially reformulated, also in light of the comment above

This was taken from inverse model and validated with evidence. Further clarified:

“The visual cortex may also modify motor feedback from the body part to the motor cortex during a motor task (Suway & Schwartz, 2019).”

2.5 "or the motor and visual cortices for non-motor and motor functions respectively, that are sent to the inferior olive (IO) via the red nucleus (pRN)": again, cf. comment 2.3 but it is also not established that non-motor content is processed by IO and/or pRN.

This was taken from inverse model and validated with evidence. Further clarified: “Whereby the actioning of the controlled object, albeit mental or motor activity, is refined in the cerebellum forward model and then fed back to the controller in which to carry out the task. Feedback occurs via the prefrontal cortex or the motor and visual cortices for non-motor and motor functions respectively, that are sent to the inferior olive (IO) via the red nucleus (pRN) that modulates the processing within the cerebellum (Burman, Darian-Smith, & Darian-Smith, 2000).”

2.6 The notion of whether the cerebellum or prefrontal areas evolved first is still being debated –

Evidence referenced:

“Evolutionarily, it has been argued that the cerebellum evolved before the frontal regions and potentially inherent in instructing this newer frontal region how to predict behavior outcomes through cognitive thought (Koziol, Budding, & Chidekel, 2012). Therefore, the main difference between planning and execution of an action is the execution of the behavior, as thought is considered to have evolved to facilitate motor control (Frank, Loughry, & O’Reilly, 2001).”

2.7 "right/left visual/verbal differences": do the authors refer to the cerebellar or cerebral cortex?

Clarified

“A lesion study by Leggio et al. (2008)…

Cognitive impairments in sequencing were attributed to cerebellar lesions in which hemispheric correlations showed decreased performance based on right/ left visual/ verbal differences.”

2.8 Please provide references for the cerebellum and basal ganglia as multisensory integration sites

Clarified:

“Functional motor and cognitive tasks are also supported through an interplay of the cortex and multisynaptic loops with the BG and cerebellum [see review (Bostan, Dum, & Strick, 2013)]”

3. Which areas of the cerebellum were reported in Ferrell et al. 2006, Klasen et al. 2011, Ulrich et al. 2016? It is important to analyze the data with respect to the cerebellar topography.

Clarified, but not reported in papers.

4. The limitations are not discussed clearly

Clarified

5. Finally it appears relatively awkward to point the reader nearly exclusively towards the authors' own recent work as future promising perspectives

Added more future considerations:

“We have already mentioned Another recent tDCS study by Ulrich et al. (2018) investigated the potential role of the mPFC in flow states, reported in earlier research, by modulating activity levels using tDCS centrally over the prefrontal region”

We also added:

“More specifically Yavari et al. (2016) explored cerebellar tDCS (tcDCS) to support ideas of forward, but not inverse, models related to cerebellar regions. Therefore, future studies investigating the interaction of tcDCS on flow states would provide further support into the role cerebellar internal models may provide in the neural mechanics of flow states.”

6. The final sentence of the manuscript is unclear and probably overstates the potential implications of this contribution.

Clarified

Minor points:

- it remains largely unclear how flow states are assessed or measured in the majority of the studies presented in this paper

Clarified

- "This hypofrontality reveals reductions" sounds odd

Clarified:

“This hypofrontality revealed a reduction in the medial prefrontal cortex”

- The authors may wish to elaborate more on introspection and arousal, as well as the neural substrates, as critical components of flow

“due to their roles in undistracted focus of the task and autotelic reward, respectively.”

- The logic of relating verbal-analytical involvement with working memory is not very straightforward

“THH’s emphasis on implicit functions supported through reduced verbal-analytical involvement. This reduction of self-monitoring encourages limited dependence on working memory (Masters, 1992), enabling performance with higher neural efficiency than explicit functions relying on working memory such as during motor tasks (Zhu et al., 2015).”

- "in the dorsal striatum of both the putamen and the ventral caudate nucleus" ?

“showing an activation of both the putamen and the ventral caudate nucleus in the dorsal striatum”

- "more recently, there has been a recent spate of flow"

Spate: a large number of similar things or events appearing or occurring in quick succession

- "This contradicts ideas purported in THH..." is an unclear statement

"This contradicts ideas assumed by THH as initiating explicit thought"

- the entire final paragraph of the THH section needs reformulating

Done - reformatted

- "In particular, cognitive binding and network synchronization..." represents a repetition

"Singer and Gray (1995)proposed that temporal characteristics of the neural activity are responsible for the binding, such that all the neuronal groups coding different features of the same object will synchronize their activity to within the range of milliseconds."

- "compared to more expertise studies" is unclear

"These results denote an emphasis on implicit functioning compared to expertise studies which tend to be associated with the explicit prefrontal areas (Engel et al., 2001)."

- "separately from typical sensory feedback" does not seem quite right, as the cerebellum relies technically on typical sensory feedback

"the internal feedback loop operates separately from a normal sensory feedback loop by running slightly ahead of the action execution"

- "completely controlled from the cerebellum": what about the basal ganglia?

"task primarily controlled from the cerebellum"

- "the dynamic interplay" should read "their"?

Fixed

- "much faster communication than the cerebellum receiving nearly four times the connections" is unclear

Clarified

- "enhanced attention component": the authors may wish to be more specific about focused attention here

“focused attention component of their flow study”

- "striatal dopamine" is a repetitively unclear statement

Addressed

- the authors may wish to replace the terms "online" and "offline" throughout the manuscript with less misintepretable terminology

Replaced

- "downregulating task irrelevant stimuli" is unclear

“downregulating focus on task irrelevant stimuli enabling cognitive processing to be more energetically efficient”

- "due to the dampening" should probably read "in order to"

"result in a dampening of the intensity of experienced flow in order to facilitate a more"

- "recognitive resistance"?

Fixed

- "Neurocognitive research on flow states have begun to provide more consistent research"

Fixed

- Why would activation and suppression patterns be neurological?

fixed – "neurocognitive"

Publication 3

PSP-P-2020-1932

The mediating role of mindfulness in explaining individual differences in flow during recreation and work.

Journal of Personality and Social Psychology: Personality Processes and Individual Differences

Dear Mr Gold,

Thank you for allowing the Journal of Personality and Social Psychology: Personality Processes and Individual Differences (JPSP:PPID) to consider your paper for publication.

Before sending manuscripts out for full review, I conduct a preliminary screening to determine both the appropriateness of the manuscript in light of JPSP:PPID's mission, as well as its likely competitiveness for publication. This can save authors and reviewers valuable time.

I believe your study is well-motivated and find the topic interesting. Nevertheless I am sorry to say that I cannot send your manuscript out for full review. As the premier empirical journal in personality psychology, papers published in JPSP typically conform to the highest standards of methodological rigor and represent significant advances in our theoretical understanding of the phenomenon under study. Unfortunately, I believe your study falls short of these high standards in several important ways.

First, as you are probably aware, recent concerns about replicability in psychological science highlight the problems associated with small samples, and make unreplicated findings based on a single small sample highly problematic to publish. Indeed, recent evidence indicates that samples of 250 or more are generally required to obtain stable parameter estimates of correlational effects among individual difference measures such as yours (Schonbrodt & Perugini, 2013). Unfortunately, 107 participants falls well below this recommended cutoff.

There are many studies which have been published with similar numbers.

Second and relatedly, the majority of studies published in JPSP consist of a package of studies building on and testing a single, or closely related, idea or set of ideas. Such packages provide an important opportunity to demonstrate that core findings replicate across samples and methods. A single study simply cannot provide the type of persuasive evidence generally required for publication in JPSP. And although we do occasionally publish papers based on single studies, when we do, such studies tend to be impressive in scope, using large, population based samples, or multi-country samples, along with rigorous and time intensive methods, such as longitudinal, diary or experimental designs. Studies such as yours based solely on cross-sectional, self-report data collected online from a convenience sample simply cannot provide the type of persuasive evidence required for publication in JPSP.

There are many studies which have been published with similar numbers and restricted cultural cohorts. This study was done to explore the field and identify potential markers and correlates to explore in larger cross- cultural studies.

Finally, reliance on strictly cross-sectional data seems particularly problematic in the present case given that a core goal involves testing a mediation model. Such models, as you know, assume a causal order among the presumed cause, mediator, and effect, and this assumption cannot be realistically justified with cross-sectional data.

Mediation models are a standard technique used across many disciplines examining the interrelationships between correlational data collected at the one time. Whilst they cannot infer causality, they are still of immense value as they tease apart patterns of relationships to determine the relative importance of direct and indirect relationships between multiple variables simultaneously.

Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford publications.

Thus, for all of these reasons, I am sorry to say that I do not believe it would be productive to consider your paper further at the present time.

I am sorry that I cannot be more positive about the current submission, particularly given the delay in communicating my decision to you. I normally try to reach an initial decision about whether to send a manuscript out for review within 1 to 2 weeks of receipt, but I have found it challenging to keep up with submissions since the covid19 shut down. Not only has my ability to focus on work been compromised, but submissions to the journal during this period have nearly doubled. Regardless of the reasons, I hope you will accept my apologies for the delay. I realize that receiving a rejection is never a happy occasion, and for this I am also sorry.

In closing, I would like to thank you again for allowing me to consider your paper. I hope my comments prove helpful to you in your ongoing research efforts, and that you will consider submitting your best future work to JPSP.

Publication 4

International Journal of Psychophysiology

Manuscript Number: INTPSY-D-20-00108

Impacts of transcranial stimulation on sports occlusion task and its frequency power profile

Dear Mr Gold,

Thank you for submitting your manuscript to International Journal of Psychophysiology.

Your manuscript was reviewed by one external reviewer and myself. Although we both find the paper interesting and timely, I regret to inform you that your paper cannot be remedied through standard revision changes and is therefore rejected.

The comments of the external reviewer are included below in order for you to understand the basis for our decision, and I hope that these incredibly thoughtful comments will help you in your future studies.

I would only add that, given the design, an overall mixed effect omnibus ANOVA should be conducted first before following up with specific comparisons.

While you may be disappointed by this decision, I would like to urge you to continue to consider International Journal of Psychophysiology for publication of future manuscripts.

Kind regards,

Yu-Chin Chiu, Ph.D.

Associate Editor

Editor and Reviewer comments:

Reviewer #1: In this manuscript, Gold and Ciorciari investigate the effects of right parietal anode-left dorsolateral prefrontal cortex cathode transcranial direct current stimulation (tDCS) montage on a soccer goalie occlusion task. In this task, participants view a short video of a soccer player kicking a soccer ball. The video is interrupted either early (just before foot-to-ball contact) or late (just after foot-to-ball contact) in the kick. When the video is interrupted, participants perform a three-alternative forced choice judgment of the resulting kick trajectory (directly toward the participant, to the left of the participant, to the right of the participant). Gold and Ciorciari investigate the effects of tDCS on performance of this task by comparing pre- and post-stimulation task performance in real and sham stimulation groups. In addition, the real/sham tDCS factor is crossed with a video game expertise factor: half the participants were relative novice gamers, while half were frequent/expert first-person-shooter game players. Finally, in addition to measuring behavioral performance, Gold and Ciorciari investigated the effects of tDCS on EEG using a spectral analysis that assessed oscillatory power in several bands: delta, theta, and (low) gamma. The manuscript seems to work towards two distinct but complementary goals: improving our understanding of the neural basis of expert perceptual anticipatory performance, and developing potential methods for neurocognitive/ neuroperceptual training. Thus, the manuscript is investigating timely and interesting topics. However, I have a number of concerns about how choices relating to the experimental methods and analysis could limit the interpretations of the results and the impact of the manuscript.

Major concerns:

1. Perhaps the key result of this study is that experts benefited from actual tDCS but not sham tDCS. I am unconvinced by this result because it appears to stem entirely from relatively poor performance of the expert real tDCS group in the pretest, rather than relatively better performance of the tDCS group in the posttest. This suggests that the sample size was too small to rely on randomization to create matched groups. In fact, the comparison of sham vs real tDCS performance at pretest in the expert group (Figure 4, left ends of lines) constitutes strong evidence of a failure of randomization. This makes the rest of the result (change in the expert tDCS group compared to change in the expert sham group) uninterpretable. The authors suggest that the failure to find further increases in the expert sham group could be due to a ceiling effect; while this is possible, it is impossible to establish this from the present results. It is also hard to believe that performance could

be at ceiling because chance performance would be 26 trials / 3 response choices =

8.67 correct trials of 26 possible, and the best-performing group (active tDCS expert posttest) averaged 12 correct trials out of 26 - above chance, but below even 50% correct.

- This study is an exploratory application (and an extension of a tDCS flow study) for hypothesis generation to further assist future studies. Therefore, the potential failure of randomization due to sample sizes was addressed in limitations

"The major limitation throughout the thesis are the small sample sizes. The results from the study on the psychometric properties (Chapter 7) should be interpreted with caution as they were drawn from a relatively small sample, which in the scope of my PhD was very difficult to accomplish and should be addressed in future research. This small sample size was also prevalent in the neurocognitive studies, yet these sample sizes were relatively not as small due to the nature of the research and the statistical tools available."

2. One of the most important factors in this study is expertise. I have several concerns about how the authors looked for differences across levels of expertise.

a. The authors motivate the expertise manipulation by discussing how expertise fosters better anticipatory categorization of others' actions (p. 4, example of tennis serve categorization in tennis experts vs. novices). However, it is not clear that the "expert" sample in the present study has relevant expertise because it is comprised of action video game players rather than soccer experts. This muddies the interpretation of the study results because it is unclear if the results will generalize to the intended expertise group—soccer experts.

- Here we defined the defined the difference between general-domain expertise vs specific-domain expertise and we explored the role specifically of general-domain expertise in the study.

b. The Method section does not adequately explain how participants were classed into expert vs. non-expert categories because it does not describe how participant video game playing frequency and aptitude were measured. How do the experimenters know that the novices "on average played videogames once a month" and what was the dispersion around this average? How were these participants recruited? Similarly, how was gaming frequency measured for the experts? What constitutes a "strong aptitude" and how was it measured?

- This was clarified in the methods section

c. Expertise is confounded with sex because the novice group was approximately 50% female while the expert group was 0% female, potentially causing problems for any comparison of novices vs. experts. If there is any relationship between soccer viewing or playing experience and sex (in addition to the apparent relationship in this sample between gaming and sec), this would be highly concerning. Even in the absence of such a relationship, there could be other systematic differences related to sex or differences in the socialization that society typically applies to males and females. Why was a 50%/50% sample of experts not recruited to match the novice group (and the general population)? If the researchers could not find such a sample of female video game experts—which seems like it would be surprising given the popularity of action video games—it would be evidence of differential socialization for the expert vs. novice group, supporting the noted confound concern. However, in such a situation, the researchers should then match the control (novice) group to the expert group by obtaining an equally-sized novice group of males, and modify all interpretation to consider that the results might be restricted to males.

- This was included in the limitation section of the paper as it was difficult to find professional female gamers.

3. I have a number of concerns relating to the statistical analysis.

a. The overall behavioral results were first analyzed with an ANOVA on all participants. Based on the reported degrees of freedom for the F test on p. 13 line 12, the authors appear to have run the ANOVA with one between-subjects factor and one within-subjects factor. In other places throughout the results, ANOVAs appear to be run on subjects of the data, or t-tests are used to compare two conditions instead of looking at the full factorial design using ANOVA. In fact, the study design was a 2 (expertise) x 2 (tDCS) x 2 (pre-test vs. post-test) factorial design with the first two factors manipulated between subjects and the final factor manipulated within subjects. The ANOVAs should be run using the full factorial design, and follow-up smaller ANOVAs and/or t-tests could be run if needed to explain the results, though the need for such follow-ups should be small since each factor has only two levels.

- The studies were run using standard tDCS and temporal occlusion testing protocols based on the way the experiments were set up.

b. One consequence of not running the full 3-way ANOVAs in each analysis of behavior and of spectral power is that the researchers evaluate effects, and then treat effects that are not sufficient to reject the null as being equal to zero. This is problematic because an effect could be, for instance, obtained in an ANOVA run on experts and the parallel effect might not be obtained in a separate ANOVA run on novices. Such a pattern of results tells us little about any potential differences between experts and novices because they are each compared to zero—i.e., no effect—rather than to one another. This is conceptually the same issue as the frequently noted "imager's fallacy." It is preferred to include both groups in the same ANOVA that considers expert vs. novice to be a between-subjects factor, and thus can evaluate differences between the groups using an interaction of other factors with the expertise factor. Similar logic applies for each of the other factors.

- This is the same consideration as the previous comment due to the fact that the two experimental studies were run with set ups that were unable to be run as 3 way ANOVAs

c. The authors report that they resorted to pairwise t-tests on the spectral power analyses on the spectral EEG data due to limitations of the analysis software. It must be possible to export the data from this software and then analyze it further in a software package of their choice, or to analyze the data from the start using a more capable software package.

- This was clarified that the while there were limitations with the statistical package it was still run with strict statistical methodologies to show a significant outcome.

d. For the spectral analyses in particular, the authors assess effects separately at 64 channels/electrodes, and at some number of distinct time bins within the 1500 ms epoch surrounding each trial. It is not clear from the Method what the time resolution of this analysis is (i.e., how many t-tests were performed per electrode)—was this a moving average window sampled at ms intervals? 10 ms? Something else? Based on the plots of these analyses, there appear to be intervals as small as 10 ms that have distinct t-test results from adjacent intervals. That would imply at least 150 t-tests per electrode over the 1500 ms epoch. If so, each spectral analysis contains 9600 t-tests. The authors adopt an alpha of .05 and do not report any correction for multiple comparisons. Because adjacent timepoints are not independent of one another, and because electrodes are not measuring independent signals, it would be far to conservative to apply a Bonferroni correction and instead use an alpha of .05 / 9600 = 5.2 x 10^-6, but an uncorrected value of .05 seems far too liberal and thus the reported results are likely to reflect a meaningful number of false positives.

- The paper clarified how brainstorm calculates t-test

4. In the spectral power analyses, many or most of the significant effects seem to

continue through the entire epoch from 500 ms before trial onset through 1000 ms after trial onset. This would seem to suggest that these do not represent changes in how trial performance relates to brain activity depending on tDCS condition; instead, it seems more likely that they relate to static effects of having been subjected to tDCS or not. However, the authors seem to be discussing these effects as if they are locked to task performance (end of p.23 of the PDF to beginning of p. 24; also, p. 24, final paragraph; also, p. 25, final paragraph; also and especially p. 25 lines 26-36, which seem to be speculating about specific cognitive processes unfolding over the course of a trial). How would the interpretation of the results change if these are sustained changes due to tDCS vs. changes in task-evoked oscillatory activity due to tDCS?

- This was addressed as a potential limitation – bleed (kindling) effect continues on and maybe a result of how an expert's brain continues to modulate after stimulation and therefore may act as a marker for particular task response.

5. I am not an expert in EEG or spectral analyses, but the trial counts (26 per condition per participant before exclusion of eyeblinks or other artifacts) seem very low for achieving any sort of stable estimate of spectral power with this sort of time resolution.

- The study removed artifact offline and online in order to utilize a significant number of trials across all the participants to satisfy the power requirements.

6. Between-subjects main effects and interactions will have power largely dictated by the number of participants in the smallest group(s), here 11 participants. This seems very small for examining between-subjects effects. The authors should explain how they

arrived at their sample size and report either an a priori power analysis or post-hoc sensitivity analyses.

- Stimulation studies are typically this sample size and accepted in this range.

7. The authors assert that tDCS participants typically cannot tell if they are receiving sham vs. real stimulation. In fact, there are many reports that participants can tell the difference, and the ability to do so often depends on the concentration of the saline solution. The authors seem to have asked their participants if they believed they were in the sham or real tDCS conditions, based on pp. 11-12. Can they fully report these data and statistically evaluate whether participants were above chance at detecting tDCS?

- This was included as a future consideration in the paper.

8. The authors do not explain how/when the tDCS electrodes were applied/removed relative to the EEG cap. How did the experimenters ensure that electricity from tDCS traveled through the brain rather than using a (potentially wet) EEG cap as the primary transmission path?

- This was clarified in the methods section.

9. Why did the authors only examine low gamma (30-59 Hz)? With 500 Hz sampling, they should also have been able to examine higher-frequency gamma band activity.

- This is the frequency domain we were interested in testing based on previous research

Minor concerns:

All Minor concerns were addressed in the paper

1. The descriptions of the results—particularly, main effects and interactions—are somewhat confusing and use non-standard language such as "main interaction effect." It would be helpful to specify the factors entering into each ANOVA, and to report F, p, and effect size estimates for each main effect and each interaction possible in that ANOVA design.

2. The text labels in Figures 7, 8, and 9 are so small as to be illegible. Presumably, the y-axes in part A of these figures are distinct electrodes, and the x-axes relate to time? The axis labels in Figures 2-6 are also likely too small, but they are legible at least at the size they are presented in the review PDF.

3. In each of the spectral analysis results figures (Figs 7A, 8A, and 9A), colors are explained as "significant t-score difference between expert (blue) and novice (red) participants after tDCS." Do the authors mean that blue corresponds to greater spectral power for experts and red corresponds to greater spectral power for novices?
- clarify

4. In several places (e.g., p. 19), results are described as "strong" but the basis for the claim of strength is unclear. Are the authors referring to a high spectral power effect size or to a large t-score or to something else? What distinguishes a strong versus weak effect in these usages?

- remove

5. As they discuss limitations of the present study, the authors assert that, "we did not test how adept people were at the soccer goalie task" in order to evaluate pre-existing differences between groups at soccer occlusion task performance. Isn't the pretest just such an evaluation? (And, as mentioned above, doesn't this pretest show that there were relevant between-groups differences?)
- clarify as a training exercise so no novelty effects

6. There are numerous grammatical errors and awkward sentence constructions throughout the manuscript, and it would benefit from a thorough proofreading and editing pass. I did not record all the instances of writing issues that I noticed, but a few that jumped out at me were:

a. p. 3 of the PDF, Abstract line 41: "…tDCS was able to modulate anticipatory behavior … in experts compared but in varying ways." Any notion of comparison requires (at least) two points, so the sentence should explain to whom experts were compared. Also, "in varying ways" is vague and cues the reader to expect the next sentence to get specific, but no specificity was presented.

b. p. 3, Abstract line 43: "tDCS may be facilitate." "Be" appears to be an extra word here.

c. p. 4, line 11: the comma between "release" and "the" should perhaps be replaced by connecting words such as "as," "because," "in that," etc. With just a comma there, the intended meaning is actually somewhat unclear.

d. p. 4, line 50-53: "experts" and "novices" should either be plural possessives (experts' performance, novices' performance), or they should be adjectives (expert performance, novice performance).

e. p. 8, beginning of Method section, lines 9-12, and again on lines 16-22: there are not complete sentences.

f. p. 9, line 7: "tested" should perhaps be "were tested"?

g. p. 22, lines 15-18: the placement of the aside "on average" should not come between "responded" and "correctly" because correctly modifies responded.

h. p. 22, lines 54-57: The construction, "why this may not … is because" works in spoken language but is confusing in written language because "why" at the start of a sentence is typically taken to be the beginning of an interrogative.. Perhaps using "The reason that this may not…" instead of "Why" would help?

i. p. 22 lines 56-59: "may be different enough" is used twice, and one (I can't tell which) is probably not needed.

j. p. 23, line 9: "to problem solve their way to a solution" is meaningless because a solution by definition solves a problem. I think the authors mean to distinguish between automatic vs. controlled decision making here?

k. p. 23, lines 14-17: "…resulted in lower performance due to no other, more well-developed strategies, left to rely on" is ambiguous in written language due to the usage of "no other." I suggest "…resulted in lower performance due to the absence of any more well-developed strategies to rely on."

Appendix 3: Research experiment documentation (Publication 4 & 5)

Testing forms for recreational participants

SWINBURNE UNIVERSITY OF TECHNOLOGY

SWINBURNE UNIVERSITY OF TECHNOLOGY

Consent Information Statement

PROJECT TITLE

Investigating brain activity and performance enhancement on video game play using neuro-modulation technology as an inductive method for flow states.

INVESTIGATORS

A/Prof. Joseph Ciorciari, Senior Lecturer (Swinburne University of Technology - School of Brain & Psychological Sciences), PhD Student : Joshua Gold (Swinburne University of Technology - School of Brain & Psychological Sciences)

EXPLANATION OF PROJECT

You have been asked to participate in this study that will investigate the brain activity associated with during video game play. This may provide information relevant to designing more effective simulation training and gaming experiences.

This study requires the participant to first fill out the Flow disposition questionnaire. Depending on how the participant scores the participant will be invited back to take part in the next portion of the study. In the next part of the study you will be asked to complete basic questionnaires, which will provide basic personal details and relevant personality (Absorption, Need for Cognition, COPE, intuition, Mindfulness and Life Satisfaction) traits. Once completing these 4 questionnaires they will be collated with the Flow disposition questionnaire and the information will be recoded and reassigned. From this point all the answers and results received about you will be completely anonymous. The actual testing will comprise of the participant playing a short game of Tetris for 30 minutes. During the game, the participant will wear a heart monitor and will have a consistent dull flickering light presented. Please note that we (or Swinburne University) do not endorse any company/ brand presented in the questionnaires or in the video game.

Adhering to standard safety guidelines, before the stimulus presentation, you will be fitted with an electrode cap to measure the electrical activity of your brain during the presentation of the materials. After testing, hair washing/ showering facilities for participants will be provided following the use of electrode paste.

Participation will require approximately 60 minutes of your time. This research is being completed through the Ph.D stream at Swinburne University of Technology and will be used for a thesis as well as possible later publications. This study is intended to provide an insight into how flow states may be associated with brain activity and attention. Furthermore, we hope to see whether differences in need for cognition, mindfulness and life satisfaction will impact on entrance into flow states.

Results will be analysed in a comparison of task performance and electrical activity of the brain across the different conditions using magnetoencephalography (MEG), and Magnetic Resonant Imaging (MRI). All equipment and laboratories have to meet strict Occupational, Health & Safety (OH&S) guidelines. Equipment is tested regularly and the operators have been sufficiently trained. MEG measures the magnetic fields of your brain. These techniques are non-invasive monitoring techniques that do not involve ionising radiation and no electrical currents are fed back to the participant. The only activity that is recorded is produced by the brain and recorded via non contact sensors for the MEG. Additional safety guidelines questionnaires will be presented to the participant before undertaking the study. Participants need be aware that the MEG and MRI testing occurs in a small shielded room in which the door will need to be closed.

All data collected from you will remain entirely confidential, as a code will be attached to your data and no name will accompany any information you will supply. Your anonymous data will only ever be accessed by the investigators mentioned above. Results of this study may be published in a peer reviewed journal or presented at conferences.

Any questions regarding the project entitled < Investigating brain activity associated with flow states during video game play > can be directed to the Senior Investigators Dr. Joseph Ciorciari of the Department/School of the Brain & Psychological Sciences Research Centre on telephone number <9214-8363 >.

NOTE: If you have any of the following conditions, please let the researcher know before you start the study, as you should not participate.

Neurological diagnosis
Psychological diagnosis
Psychological hospitalization
Recent hospitalization for surgery/illness
Psychotropic medications
Received shot (i.e. flu, allergies, pain) in the left arm in past 7 days
Non-removable metal or tattoos around head
Non-corrected vision or hearing
Have sought treatment for problems with motor coordination
Allergy/sensitivity to latex
Use of Depo-Provera in the left arm
Pregnant or could be pregnant
History of the following:
- Claustrophobia
- Learning difficulty
- Attention deficit
- Severe brain injury or concussion in past year
- Seizures
- Fainting
- Migraines
- High blood pressure

- Diabetes
- Heart disease
- Drug or alcohol treatment in past year
- Illicit drug use in past month
- No more than 4 alcoholic drinks in the past 24 hours
- Ferrous metal imbedded in the body (must be MRI safe)

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

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

General Questions

What is your age?

What is your sex?

Are you left or right handed?

How often do you play video games?
Every day
2-3 times a week
Once a week
Once a month
Once a year
Never

What are the most common video games you play?

How would you rate your proficiency at first person shooter video games?

1 – Don't know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

How would you rate your proficiency at Tetris?

1 – Don't know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

When was the last time you played Tetris?

Tellegen Absorption Scale

This questionnaire consists of questions about experiences that you may have had in your life. We are interested in how often you have these experiences. It is important, however, that your answers show how often these experiences happen to you when you are not under the influence of alcohol or drugs. Please place the number that best represents on the line in front of the question.

1	2	3	4	5
extremely uncharacteristic of me	somewhat uncharacteristic of me	uncertain	somewhat characteristic of me	extremely characteristic of me

_____ 1. Sometimes I feel and experience things as I did when I was a child.
_____ 2. I can be greatly moved by eloquent or poetic language.
_____ 3. While watching a movie, a TV show, or a play, I may sometimes become so involved that I forget about myself and my surroundings and experience the story as if it were real and as if I were taking part in it.
_____ 4.If I stare at a picture and then look away from it, I can sometimes 'see' an image of the picture, almost as if I were still looking at it.
_____ 5. Sometimes I feel as if my mind could envelop the whole earth.
_____ 6. I like to watch cloud shapes in the sky.
_____ 7. If I wish, I can imagine (or daydream) some things so vividly that they hold my attention as a good movie or a story does.
_____ 8. I think I really know what some people mean when they talk about mystical experiences.
_____ 9. I sometimes 'step outside' my usual self and experience an entirely different state of being.
_____ 10. Textures-such as wool, sand, wood-sometimes remind me of colours or music.
_____ 11. Sometimes I experience things as if they were doubly real.
_____ 12. When I listen to music, I can get so caught up in it that I don't notice anything else.
_____ 13. If I wish, I can imagine that my whole body is so heavy that I could not move it if I wanted to.
_____ 14. I can often somehow sense the presence of another person before I actually see or hear him/her.
_____ 15. The crackle and flames of a wood fire stimulates my imagination.
_____ 16. It is sometimes possible for me to be completely immersed in nature or art and to feel as if my whole state of consciousness has somehow been temporarily altered.
_____ 17. Different colours have distinctive and special meanings for me.
_____ 18. I am able to wander off into my own thought while doing a routine task and actually forget that I am doing the task, and then find a few minutes later that I have completed it.
_____ 19. I can sometimes recollect certain past experiences in my life with such clarity and vividness that it is like living them again or almost so.

______ 20. Things that might seem meaningless to others often make sense to me.
______ 21. While acting in a play, I think I would really feel the emotions of the character and “become” her/him for the time being, forgetting both myself and the audience.
______ 22. My thoughts often do not occur as words but as visual images.
______ 23. I often take delight in small things (like the five pointed star shape that appears when you cut an apple across the core or the colours in soap bubbles).
______ 24. When listening to organ music or other powerful music, I sometimes feel as if I am being lifted into the air.
______ 25. Sometimes I can change noise into music by the way I listen to it.
______ 26. Some of my most vivid memories are called up by scents and smells.
______ 27. Certain pieces of music remind me of pictures or moving patterns of colour.
______ 28. I often know what someone is going to say before he or she says it.
______ 29. I often have “physical memories” for example, after I have been swimming I may still feel as if I am in the water
______ 30. The sound of a voice can be so fascinating to me that I can just go on listening to it.
______ 31. At times I somehow feel the presence of someone who is not physically there.
______ 32. Sometimes thoughts and images come to me without the slightest effort on my part.
______ 33. I find that different odors have different colours.
______ 34. I can be deeply moved by a sunset.

Need for Cognition Scale

For each of the statements below, please indicate whether or not the statement is characteristic of you or of what you believe. For example, if the statement is extremely uncharacteristic of you or of what you believe about yourself (not at all like you) please place a "1" on the line to the left of the statement. If the statement is extremely characteristic of you or of what you believe about yourself (very much like you) please place a "5" on the line to the left of the statement. You should use the following scale as you rate each of the statements below. Please place the number that best represents on the line in front of the question.

1	2	3	4	5
extremely uncharacteristic of me	somewhat uncharacteristic of me	uncertain	somewhat characteristic of me	extremely characteristic of me

1. ____ I really enjoy a task that involves coming up with new solutions to problems.
2. ____ I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
3. ____ I tend to set goals that can be accomplished only by expending considerable mental effort
4. ____ I am usually tempted to put more thought into a task than the job minimally requires.
5. ____ Learning new ways to think doesn't excite me very much.
6. ____ I am hesitant about making important decisions after thinking about them.
7. ____ I usually end up deliberating about issues even when they do not affect me personally.
8. ____ I prefer to just let things happen rather than try to understand why they turned out that way.
9. ____ I have difficulty thinking in new and unfamiliar situations.
10. ____ The idea of relying on thought to make my way to the top does not appeal to me.
11. ____ The notion of thinking abstractly is not appealing to me.
12. ____ I am an intellectual
13. ____ I only think as hard as I have to.
14. ____ I don't reason well under pressure.
15. ____ I like tasks that require little thought once I've learned them.
16. ____ I prefer to think about small, daily projects to long-term ones.
17. ____ I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
18. ____ I find little satisfaction in deliberating hard and for long hours.
19. ____ I more often talk with other people about the reasons for and possible solutions to international problems than about gossip or tidbits of what famous people are doing.
20. ____ These days, I see little chance for performing well, even in "intellectual" jobs, unless one knows the right people.
21. ____ More often than not, more thinking just leads to more errors.
22. ____ I don't like to have the responsibility of handling a situation that requires a lot of thinking.
23. ____ I appreciate opportunities to discover the strengths and weaknesses of my own reasoning.

24.____ I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
25.____ Thinking is not my idea of fun.
26.____ I try to anticipate and avoid situations where there is a likely chance I will have to think in depth about something.
27.____ I prefer watching educational to entertainment programs.
28. ____I think best when those around me are very intelligent.
29.____ I prefer my life to be filled with puzzles that I must solve.
30.____ I would prefer complex to simple problems.
31.____ Simply knowing the answer rather than understanding the reasons for the answer to a problem is fine with me.
32.____ It's enough for me that something gets the job done, I don't care how or why it works.
33.____ Ignorance is bliss.
34.____ I enjoy thinking about an issue even when the results of my thought will have no effect on the outcome of the issue.

Five Facet Mindfulness Questionnaire

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you. Please place the number that best represents on the line in front of the question.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

_____ 1. When I'm walking, I deliberately notice the sensations of my body moving.
_____ 2. I'm good at finding words to describe my feelings.
_____ 3. I criticize myself for having irrational or inappropriate emotions.
_____ 4. I perceive my feelings and emotions without having to react to them.
_____ 5. When I do things, my mind wanders off and I'm easily distracted.
_____ 6. When I take a shower or bath, I stay alert to the sensations of water on my body.
_____ 7. I can easily put my beliefs, opinions, and expectations into words.
_____ 8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.
_____ 9. I watch my feelings without getting lost in them.
_____ 10. I tell myself I shouldn't be feeling the way I'm feeling.
_____ 11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.
_____ 12. It's hard for me to find the words to describe what I'm thinking.
_____ 13. I am easily distracted.
_____ 14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.
_____ 15. I pay attention to sensations, such as the wind in my hair or sun on my face.
_____ 16. I have trouble thinking of the right words to express how I feel about things
_____ 17. I make judgments about whether my thoughts are good or bad.
_____ 18. I find it difficult to stay focused on what's happening in the present.
_____ 19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.
_____ 20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.
_____ 21. In difficult situations, I can pause without immediately reacting.
_____ 22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.
_____ 23. It seems I am "running on automatic" without much awareness of what I'm doing.
_____ 24. When I have distressing thoughts or images, I feel calm soon after.
_____ 25. I tell myself that I shouldn't be thinking the way I'm thinking.
_____ 26. I notice the smells and aromas of things.
_____ 27. Even when I'm feeling terribly upset, I can find a way to put it into words.
_____ 28. I rush through activities without being really attentive to them.
_____ 29. When I have distressing thoughts or images I am able just to notice them without reacting.
_____ 30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.

_____ 31. I notice visual elements in art or nature, such as colours, shapes, textures, or patterns of light and shadow.
_____ 32. My natural tendency is to put my experiences into words.
_____ 33. When I have distressing thoughts or images, I just notice them and let them go.
_____ 34. I do jobs or tasks automatically without being aware of what I'm doing.
_____ 35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.
_____ 36. I pay attention to how my emotions affect my thoughts and behaviour.
_____ 37. I can usually describe how I feel at the moment in considerable detail.
_____ 38. I find myself doing things without paying attention.
_____ 39. I disapprove of myself when I have irrational ideas.

Flourishing Scale

Below are 8 statements with which you may agree or disagree. Using the 1–7 scale below, indicate your agreement with each item by indicating the number of response before each statement.

- _7 – Strongly agree
- _6 – Agree
- _5 – Slightly agree
- _4 – Neither agree nor disagree
- _3 – Slightly disagree
- _2 – Disagree
- _1 – Strongly disagree

____ I lead a purposeful and meaningful life
____ My social relationships are supportive and rewarding
____ I am engaged and interested in my daily activities
____ I actively contribute to the happiness and well-being of others
____ I am competent and capable in the activities that are important to me
____ I am a good person and live a good life
____ I am optimistic about my future
_____ People respect me

Scale of Positive and Negative Experience

Please think about what you have been doing and experiencing during the past four weeks. Then report how much you experienced each of the following feelings, using the scale below. For each item, select a number from 1 to 5, and indicate that number on your response sheet.

1. Very Rarely or Never
2. Rarely
3. Sometimes
4. Often
5. Very Often or Always

Positive ____________________
Negative ____________________
Good ____________________
Bad ____________________
Pleasant ____________________
Unpleasant ____________________
Happy ____________________
Sad ____________________
Afraid ____________________
Joyful ____________________
Angry ____________________
Contented ____________________

Satisfaction with Life Scale

Below are five statements that you may agree or disagree with. Using the 1 - 7 scale below, indicate your agreement with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding.

- 7 - Strongly agree
- 6 - Agree
- 5 - Slightly agree
- 4 - Neither agree nor disagree
- 3 - Slightly disagree
- 2 - Disagree
- 1 - Strongly disagree

____ In most ways my life is close to my ideal.

____ The conditions of my life are excellent.

____ I am satisfied with my life.

____ So far I have gotten the important things I want in life.

____ If I could live my life over, I would change almost nothing.

Brief COPE

These items deal with ways you cope with the stress in your life. There are many ways to try to deal with problems. These items ask what you do to cope with stress. Obviously, different people deal with things in different ways, but I'm interested in how you deal with it. Each item says something about a particular way of coping. I want to know to what extent you do what the item says. How much or how frequently. Don't answer on the basis of whether it works or not—just whether or not you do it. Use these response choices. Try to rate each item separately in your mind from the others. Make your answers as true FOR YOU as you can.

1 = I haven't been doing this at all
2 = I've been doing this a little bit
3 = I've been doing this a medium amount
4 = I've been doing this a lot

___ 1. I turn to work or other activities to take my mind off things.
___ 2. I concentrate my efforts on doing something about the situation I'm in.
___ 3. I say to myself "this isn't real.".
___ 4. I use alcohol or other drugs to make myself feel better.
___ 5. I get emotional support from others.
___ 6. I give up trying to deal with it.
___ 7. I take action to try to make the situation better.
___ 8. I refuse to believe that it has happened.
___ 9. I say things to let my unpleasant feelings escape.
___ 10. I get help and advice from other people.
___ 11. I use alcohol or other drugs to help me get through it.
___ 12. I try to see it in a different light, to make it seem more positive.
___ 13. I criticize myself.
___ 14. I try to come up with a strategy about what to do.
___ 15. I get comfort and understanding from someone.
___ 16. I give up the attempt to cope.
___ 17. I look for something good in what is happening.
___ 18. I make jokes about it.
___ 19. I do something to think about it less, such as going to movies, watching TV, reading, daydreaming, sleeping, or shopping.
___ 20. I accept the reality of the fact that it has happened.
___ 21. I express my negative feelings.
___ 22. I try to find comfort in my religion or spiritual beliefs.
___ 23. I try to get advice or help from other people about what to do.
___ 24. I learn to live with it.
___ 25. I think hard about what steps to take.
___ 26. I blame myself for things that happened.
___ 27. I pray or meditate.
___ 28. I make fun of the situation.

Dispositional Flow Scale

Please fill in the activity you feel most engaged in and then answer the following questions in relation to your experience of your chosen activity. These questions relate to the thoughts and feelings you may experience during participation in your activity. You may experience these characteristics some of the time, all of the time, or none of the time. There are no right or wrong answers. Think about how often you experience each characteristic during your activity, then circle, or insert in the "Score" box, the number that best matches your experience.

What is the activity you most feel engaged in? ________________________________

Score		When participating in your FLOW activity	Never	Rarely	Sometimes	Frequently	Often
	1	I am challenged, but I believe my skills will allow me to meet the challenge	1	2	3	4	5
	2	I make the correct movements without thinking about trying to do so	1	2	3	4	5
	3	I know clearly what I want to do	1	2	3	4	5
	4	It is really clear to me how my performance is going	1	2	3	4	5
	5	My attention is focused entirely on what I am doing	1	2	3	4	5
	6	I have a sense of control over what I am doing	1	2	3	4	5
	7	I am not concerned with what others may be thinking of me	1	2	3	4	5
	8	Time seems to alter (either slows down or speeds up)	1	2	3	4	5
	9	I really enjoy the experience	1	2	3	4	5
	10	My abilities match the high challenge of the situation	1	2	3	4	5
	11	Things just seem to happen automatically	1	2	3	4	5
	12	I have a strong sense of what I want to do	1	2	3	4	5
	13	I am aware of how well I am performing	1	2	3	4	5
	14	It is no effort to keep my mind on what is happening	1	2	3	4	5
	15	I feel like I can control what I am doing	1	2	3	4	5
	16	I am not concerned with how others may be evaluating me	1	2	3	4	5
	17	The way time passes seems to be different from normal	1	2	3	4	5
	18	I love the feeling of the performance and want to capture it again	1	2	3	4	5
	19	I feel I am competent enough to meet the high demands of the situation	1	2	3	4	5
	20	I perform automatically, without thinking too much	1	2	3	4	5
	21	I know what I want to achieve	1	2	3	4	5

	22	I have a good idea while I am performing about how well I am doing	1	2	3	4	5
	23	I have total concentration	1	2	3	4	5
	24	I have a feeling of total control	1	2	3	4	5
	25	I am not concerned with how I am presenting myself	1	2	3	4	5
	26	It feels like time goes by quickly	1	2	3	4	5
	27	The experience leaves me feeling great	1	2	3	4	5
	28	The challenge and my skills are at an equally high level	1	2	3	4	5
	29	I do things spontaneously and automatically without having to think	1	2	3	4	5
	30	My goals are clearly defined	1	2	3	4	5
	31	I can tell by the way I am performing how well I am doing	1	2	3	4	5
	32	I am completely focused on the task at hand	1	2	3	4	5
	33	I feel in total control of my body	1	2	3	4	5
	34	I am not worried about what others may be thinking of me	1	2	3	4	5
	35	I lose my normal awareness of time	1	2	3	4	5
	36	The experience is extremely rewarding	1	2	3	4	5

Types of Intuition Scale (TIntS)

We are interested in how you make decisions and solve problems in your life. Read each of the following statements and rate the extent to which you would agree that that statement is true of you using the scale below. These items have no right or wrong answers; just respond based on what is true for you. Write the number corresponding to your response on the line before each statement.

1	2	3	4	5
Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree

__ 1. I usually make a better decision if I sleep on it first.
__ 2. I've had enough experience to just know what I need to do most of the time without trying to figure it out every time.
__ 3. I tend to use my heart as a guide for my actions.
__4. After working on a problem for a long time, I like to set it aside for a while before making a final decision.
__ 5. My approach to problem solving relies heavily on my past experience.
__ 6. I generally don't depend on my feelings to help me make decisions.
__ 7. When working on a problem, I prefer to work slowly so that there is time for all the pieces to come together.
__ 8. When I have much experience or knowledge about a problem, I almost always trust my intuitions.
__ 9. I think it is foolish to make important decisions based on feelings.
__ 10. Ambiguity makes me very uncomfortable.
__ 11. When I have little experience with a problem, I prefer not to trust my intuition.
__ 12. When making decisions, I value my feelings and hunches just as much as I value facts.
__ 13. When I get stuck working on a problem, the answer frequently comes to me suddenly at some later point in time.
__ 14. My instincts in my areas of expertise are much better than in areas I do not know well.
__ 15. I prefer to follow my head rather than my heart.
__ 16. I am not very good at keeping in mind the big picture when working on a problem.
__ 17. My intuitive judgments are based on a few key pieces of information.
__ 18. Rather than spend my time trying to think of how to deal with a problem situation, I prefer to use my emotional hunches.
__ 19. I enjoy thinking in abstract terms.
__ 20. When I analyze my problems, I tend to miss important information and make a worse decision than if I had trusted my intuition.
__ 21. If I have to, I can usually give reasons for my intuitions.
__ 22. I often make decisions based on my gut feelings, even when the decision is contrary to objective information.
__ 23. I would rather think in terms of theories than facts.

__ 24. I rely on my intuition when I have little experience or knowledge about a problem.
__ 25. My intuitions come to me very quickly.
__ 26. I like to rely on my intuitive impressions.
__ 27. When I have a specific plan for solving a problem, I always stick to it and do not allow myself to get distracted.
__ 28. When I trust my intuition, I come to the same conclusion as if I had carefully analyzed the situation.
__ 29. I believe in trusting my hunches.
__ 30. Even after I have a specific plan for solving a problem, I make an effort to remain open to other approaches.
__ 31. In a familiar area, I am comfortable making a decision based on limited information when I have to.
__ 32. I rarely allow my emotional reactions to override logic.
__ 33. When making decisions, I try to suspend my assumptions and prior beliefs.
__ 34. I am more likely to trust my intuition on complex problems than simpler ones.
__ 35. There is a logical justification for most of my intuitive judgments.
__ 36. I almost always trust my intuition because I think it is a bad idea to analyse everything.
__ 37. Intuition is an accurate and reliable shortcut for problems that would otherwise require a lot of analysis.

SWINBURNE UNIVERSITY OF TECHNOLOGY

INFORMED CONSENT

PROJECT TITLE:

Investigating brain activity associated with flow states during video game play

INVESTIGATORS:

Assoc. Prof Joseph Ciorciari, Senior Lecturer (Swinburne University of Technology), Joshua Gold (Swinburne University of Technology - School of the Brain & Psychological Sciences)

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

In relation to this project, please circle your response to the following:

- I agree to be interviewed by the researcher **Yes** **No**
- I agree to allow the interview to be recorded by electronic device **Yes** **No**
- I agree to make myself available for further information if required **Yes** **No**
- I agree to complete questionnaires asking me about

  [Absorption, Need for Cognition, COPE, Intuition, Mindfulness and Life Satisfaction] **Yes**

  No

3. I acknowledge that:
   (a) my participation is voluntary and that I am free to withdraw from the project at any time without explanation;
   (b) the Swinburne project is for the purpose of research and not for profit;
   (c) any identifiable information about me which is gathered in the course of and as the result of my participating in this project will be (i) collected and retained for the purpose of this project and (ii) accessed and analysed by the researcher(s) for the purpose of conducting this project;
   (d) my anonymity is preserved and I will not be identified in publications or otherwise without my express written consent.

By signing this document you agree to participate in this project.
As you will be undergoing MEG analysis certain information pertaining to your medical history is required to be obtained for your safety.

Please indicate to the researcher if any of the following are relevant to you. However, it is not necessary to indicate any specifics, as these questions are only for screening purposes.

▪ Do you have history of any Psychiatric or Neurological Condition?	**Yes**	**No**
▪ Do you suffer from Epilepsy?	**Yes**	**No**
▪ Is there a history of Epilepsy in your family?	**Yes**	**No**
▪ Have you ever suffered from convulsions?	**Yes**	**No**
▪ Do you suffer from a medical condition that requires medication?	**Yes**	**No**
▪ Do you have a history of head trauma?	**Yes**	**No**
▪ Do you have a history of claustrophobia?	**Yes**	**No**

In giving consent, the participant states that they do not have or not aware of having the aforementioned medical concerns.

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

Name of Participant:
………………………………………………………………………………

Signature & Date: ……………………………………………………………

* NAME OF AUTHORISED REPRESENTATIVE: Joshua Gold
POSITION: Researcher ....
SIGNATURE...DATE...................

NAME/S OF PRINCIPAL INVESTIGATOR/S: Dr Joseph Ciorciari, Joshua Gold
SIGNATURE... **DATE** ....
SIGNATURE... **DATE** ....
SIGNATURE... **DATE** ....
SIGNATURE... **DATE** ....
SIGNATURE... **DATE** ....

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human*

Research. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.

Testing forms for occupational participants

SWINBURNE UNIVERSITY OF TECHNOLOGY

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Consent Information Statement

PROJECT TITLE
Investigating brain activity and performance enhancement on video game play using neuro-modulation technology as an inductive method for flow states.

INVESTIGATORS
A/Prof. Joseph Ciorciari, Senior Lecturer (Swinburne University of Technology - School of Brain & Psychological Sciences), Joshua Gold (Swinburne University of Technology - School of Brain & Psychological Sciences)

EXPLANATION OF PROJECT

You have been asked to participate in this study that will investigate the brain activity associated with during video game play. This may provide information relevant to designing more effective simulation training and gaming experiences.

This study requires the participant to first fill out the Flow disposition questionnaire. Depending on how the participant scores the participant will be invited back to take part in the next portion of the study. In the next part of the study you will be asked to complete basic questionnaires, which will provide basic personal details and relevant personality (Absorption, Need for Cognition, COPE, intuition, Mindfulness and Life Satisfaction) traits. Once completing these 4 questionnaires they will be collated with the Flow disposition questionnaire and the information will be recoded and reassigned. From this point all the answers and results received about you will be completely anonymous. The actual testing will comprise of two test trials 30 minutes each, in which you will be asked to play a first person shooter game. During the game, the participant will wear a heart monitor and will have a consistent dull flickering light presented. Please note that we (or Swinburne University) do not endorse any company/ brand presented in the questionnaires or in the video game.

Adhering to standard safety guidelines, before the stimulus presentation, you will be fitted with an electrode cap to measure the electrical activity of your brain during the presentation of the materials. After testing, hair washing/ showering facilities for participants will be provided following the use of electrode paste.

Participation will require approximately 120 minutes of your time. This research is being completed through the Ph.D stream at Swinburne University of Technology and will be used for a thesis as well as possible later publications. This study is intended to provide an insight into how flow states may be associated with brain activity and attention. Furthermore, we hope to see whether differences in need for cognition, mindfulness and life satisfaction will impact on entrance into flow states.

Results will be analysed in a comparison of task performance and electrical activity of the brain across the different conditions using electroencephalography (EEG). All equipment and laboratories have to meet strict Occupational, Health & Safety (OH&S) guidelines. Equipment is tested regularly and the operators have been sufficiently trained. EEG measures the electrical current produced by the brain. These techniques are non-invasive monitoring techniques that do not involve ionising radiation and no electrical currents are fed back to the participant. The only activity that is recorded is produced by the brain and recorded via electrodes sitting on the scalp for the EEG. Additional safety guidelines questionnaires will be presented to the participant before undertaking the study.

Please note that first person shooters contains simulated violence and if at any time you do not wish to continue or wish to withdraw from this study you are free to do so. At no time will you be placed at any risk by this experiment, if you feel you are in any personal risk or discomfort please notify the researchers and the study will cease immediately. If you wish to see the final results of this study inform the researchers and on completion of study a copy will be made available for you.

All data collected from you will remain entirely confidential, as a code will be attached to your data and no name will accompany any information you will supply. Your anonymous data will only ever be accessed by the investigators mentioned above. Results of this study may be published in a peer reviewed journal or presented at conferences.

Any questions regarding the project entitled < Investigating brain activity associated with flow states during video game play > can be directed to the Senior Investigators Dr. Joseph Ciorciari of the Department/School of the Brain & Psychological Sciences Research Centre on telephone number <9214-8363 >.

NOTE: If you have any of the following conditions, please let the researcher know before you start the study, as you should not participate.

Neurological diagnosis
Psychological diagnosis
Psychological hospitalization
Recent hospitalization for surgery/illness
Psychotropic medications
Received shot (i.e. flu, allergies, pain) in the left arm in past 7 days
Non-removable metal or tattoos around head
Non-corrected vision or hearing
Have sought treatment for problems with motor coordination
Allergy/sensitivity to latex
Use of Depo-Provera in the left arm
Pregnant or could be pregnant
History of the following:
- Claustrophobia
- Learning difficulty
- Attention deficit
- Severe brain injury or concussion in past year
- Seizures
- Fainting

- Migraines
- High blood pressure
- Diabetes
- Heart disease
- Drug or alcohol treatment in past year
- Illicit drug use in past month
- No more than 4 alcoholic drinks in the past 24 hours
- Ferrous metal imbedded in the body (must be MRI safe)

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

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

General Questions

What is your age?

What is your sex?

Are you left or right handed?

How often do you play video games?
Every day
2-3 times a week
Once a week
Once a month
Once a year
Never

What are the most common video games you play?

How would you rate your proficiency at first person shooter video games?

1 – Don't know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

How would you rate your proficiency at ______________________________?

1 – Don't know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

Tellegen Absorption Scale

This questionnaire consists of questions about experiences that you may have had in your life. We are interested in how often you have these experiences. It is important, however, that your answers show how often these experiences happen to you when you are not under the influence of alcohol or drugs. Please place the number that best represents on the line in front of the question.

1	2	3	4	5
extremely uncharacteristic of me	somewhat uncharacteristic of me	uncertain	somewhat characteristic of me	extremely characteristic of me

______ 1. Sometimes I feel and experience things as I did when I was a child.
______ 2. I can be greatly moved by eloquent or poetic language.
______ 3. While watching a movie, a TV show, or a play, I may sometimes become so involved that I forget about myself and my surroundings and experience the story as if it were real and as if I were taking part in it.
______ 4.If I stare at a picture and then look away from it, I can sometimes 'see' an image of the picture, almost as if I were still looking at it.
______ 5. Sometimes I feel as if my mind could envelop the whole earth.
______ 6. I like to watch cloud shapes in the sky.
______ 7. If I wish, I can imagine (or daydream) some things so vividly that they hold my attention as a good movie or a story does.
______ 8. I think I really know what some people mean when they talk about mystical experiences.
______ 9. I sometimes 'step outside' my usual self and experience an entirely different state of being.
______ 10. Textures-such as wool, sand, wood-sometimes remind me of colours or music.
______ 11. Sometimes I experience things as if they were doubly real.
______ 12. When I listen to music, I can get so caught up in it that I don't notice anything else.
______ 13. If I wish, I can imagine that my whole body is so heavy that I could not move it if I wanted to.
______ 14. I can often somehow sense the presence of another person before I actually see or hear him/her.
______ 15. The crackle and flames of a wood fire stimulates my imagination.
______ 16. It is sometimes possible for me to be completely immersed in nature or art and to feel as if my whole state of consciousness has somehow been temporarily altered.
______ 17. Different colours have distinctive and special meanings for me.
______ 18. I am able to wander off into my own thought while doing a routine task and actually forget that I am doing the task, and then find a few minutes later that I have completed it.
______ 19. I can sometimes recollect certain past experiences in my life with such clarity and vividness that it is like living them again or almost so.

______ 20. Things that might seem meaningless to others often make sense to me.
______ 21. While acting in a play, I think I would really feel the emotions of the character and "become" her/him for the time being, forgetting both myself and the audience.
______ 22. My thoughts often do not occur as words but as visual images.
______ 23. I often take delight in small things (like the five pointed star shape that appears when you cut an apple across the core or the colours in soap bubbles).
______ 24. When listening to organ music or other powerful music, I sometimes feel as if I am being lifted into the air.
______ 25. Sometimes I can change noise into music by the way I listen to it.
______ 26. Some of my most vivid memories are called up by scents and smells.
______ 27. Certain pieces of music remind me of pictures or moving patterns of colour.
______ 28. I often know what someone is going to say before he or she says it.
______ 29. I often have "physical memories" for example, after I have been swimming I may still feel as if I am in the water
______ 30. The sound of a voice can be so fascinating to me that I can just go on listening to it.
______ 31. At times I somehow feel the presence of someone who is not physically there.
______ 32. Sometimes thoughts and images come to me without the slightest effort on my part.
______ 33. I find that different odors have different colours.
______ 34. I can be deeply moved by a sunset.

Need for Cognition Scale

For each of the statements below, please indicate whether or not the statement is characteristic of you or of what you believe. For example, if the statement is extremely uncharacteristic of you or of what you believe about yourself (not at all like you) please place a "1" on the line to the left of the statement. If the statement is extremely characteristic of you or of what you believe about yourself (very much like you) please place a "5" on the line to the left of the statement. You should use the following scale as you rate each of the statements below. Please place the number that best represents on the line in front of the question.

1	2	3	4	5
extremely uncharacteristic of me	somewhat uncharacteristic of me	uncertain	somewhat characteristic of me	extremely characteristic of me

1. ____ I really enjoy a task that involves coming up with new solutions to problems.
2. ____ I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
3. ____ I tend to set goals that can be accomplished only by expending considerable mental effort
4. ____ I am usually tempted to put more thought into a task than the job minimally requires.
5. ____ Learning new ways to think doesn't excite me very much.
6. ____ I am hesitant about making important decisions after thinking about them.
7. ____ I usually end up deliberating about issues even when they do not affect me personally.
8. ____ I prefer to just let things happen rather than try to understand why they turned out that way.
9. ____ I have difficulty thinking in new and unfamiliar situations.
10. ____ The idea of relying on thought to make my way to the top does not appeal to me.
11. ____ The notion of thinking abstractly is not appealing to me.
12. ____ I am an intellectual
13. ____ I only think as hard as I have to.
14. ____ I don't reason well under pressure.
15. ____ I like tasks that require little thought once I've learned them.
16. ____ I prefer to think about small, daily projects to long-term ones.
17. ____ I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
18. ____ I find little satisfaction in deliberating hard and for long hours.
19. ____ I more often talk with other people about the reasons for and possible solutions to international problems than about gossip or tidbits of what famous people are doing.
20. ____ These days, I see little chance for performing well, even in "intellectual" jobs, unless one knows the right people.
21. ____ More often than not, more thinking just leads to more errors.
22. ____ I don't like to have the responsibility of handling a situation that requires a lot of thinking.
23. ____ I appreciate opportunities to discover the strengths and weaknesses of my own reasoning.

24.____ I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
25.____ Thinking is not my idea of fun.
26.____ I try to anticipate and avoid situations where there is a likely chance I will have to think in depth about something.
27.____ I prefer watching educational to entertainment programs.
28. ____I think best when those around me are very intelligent.
29.____ I prefer my life to be filled with puzzles that I must solve.
30.____ I would prefer complex to simple problems.
31.____ Simply knowing the answer rather than understanding the reasons for the answer to a problem is fine with me.
32.____ It's enough for me that something gets the job done, I don't care how or why it works.
33.____ Ignorance is bliss.
34.____ I enjoy thinking about an issue even when the results of my thought will have no effect on the outcome of the issue.

Five Facet Mindfulness Questionnaire

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you. Please place the number that best represents on the line in front of the question.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

_____ 1. When I'm walking, I deliberately notice the sensations of my body moving.
_____ 2. I'm good at finding words to describe my feelings.
_____ 3. I criticize myself for having irrational or inappropriate emotions.
_____ 4. I perceive my feelings and emotions without having to react to them.
_____ 5. When I do things, my mind wanders off and I'm easily distracted.
_____ 6. When I take a shower or bath, I stay alert to the sensations of water on my body.
_____ 7. I can easily put my beliefs, opinions, and expectations into words.
_____ 8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.
_____ 9. I watch my feelings without getting lost in them.
_____ 10. I tell myself I shouldn't be feeling the way I'm feeling.
_____ 11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.
_____ 12. It's hard for me to find the words to describe what I'm thinking.
_____ 13. I am easily distracted.
_____ 14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.
_____ 15. I pay attention to sensations, such as the wind in my hair or sun on my face.
_____ 16. I have trouble thinking of the right words to express how I feel about things
_____ 17. I make judgments about whether my thoughts are good or bad.
_____ 18. I find it difficult to stay focused on what's happening in the present.
_____ 19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.
_____ 20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.
_____ 21. In difficult situations, I can pause without immediately reacting.
_____ 22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.
_____ 23. It seems I am "running on automatic" without much awareness of what I'm doing.
_____ 24. When I have distressing thoughts or images, I feel calm soon after.
_____ 25. I tell myself that I shouldn't be thinking the way I'm thinking.
_____ 26. I notice the smells and aromas of things.
_____ 27. Even when I'm feeling terribly upset, I can find a way to put it into words.
_____ 28. I rush through activities without being really attentive to them.
_____ 29. When I have distressing thoughts or images I am able just to notice them without reacting.
_____ 30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.

_____ 31. I notice visual elements in art or nature, such as colours, shapes, textures, or patterns of light and shadow.
_____ 32. My natural tendency is to put my experiences into words.
_____ 33. When I have distressing thoughts or images, I just notice them and let them go.
_____ 34. I do jobs or tasks automatically without being aware of what I'm doing.
_____ 35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.
_____ 36. I pay attention to how my emotions affect my thoughts and behaviour.
_____ 37. I can usually describe how I feel at the moment in considerable detail.
_____ 38. I find myself doing things without paying attention.
_____ 39. I disapprove of myself when I have irrational ideas.

Flourishing Scale

Below are 8 statements with which you may agree or disagree. Using the 1–7 scale below, indicate your agreement with each item by indicating the number of response before each statement.

- _7 – Strongly agree
- _6 – Agree
- _5 – Slightly agree
- _4 – Neither agree nor disagree
- _3 – Slightly disagree
- _2 – Disagree
- _1 – Strongly disagree

____ I lead a purposeful and meaningful life
____ My social relationships are supportive and rewarding
____ I am engaged and interested in my daily activities
____ I actively contribute to the happiness and well-being of others
____ I am competent and capable in the activities that are important to me
____ I am a good person and live a good life
____ I am optimistic about my future
_____ People respect me

Scale of Positive and Negative Experience

Please think about what you have been doing and experiencing during the past four weeks. Then report how much you experienced each of the following feelings, using the scale below. For each item, select a number from 1 to 5, and indicate that number on your response sheet.

1. Very Rarely or Never
2. Rarely
3. Sometimes
4. Often
5. Very Often or Always

Positive	____________________
Negative	____________________
Good	____________________
Bad	____________________
Pleasant	____________________
Unpleasant	____________________
Happy	____________________
Sad	____________________
Afraid	____________________
Joyful	____________________
Angry	____________________
Contented	____________________

Satisfaction with Life Scale

Below are five statements that you may agree or disagree with. Using the 1 - 7 scale below, indicate your agreement with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding.

- 7 - Strongly agree
- 6 - Agree
- 5 - Slightly agree
- 4 - Neither agree nor disagree
- 3 - Slightly disagree
- 2 - Disagree
- 1 - Strongly disagree

____ In most ways my life is close to my ideal.

____ The conditions of my life are excellent.

____ I am satisfied with my life.

____ So far I have gotten the important things I want in life.

____ If I could live my life over, I would change almost nothing.

Brief COPE

These items deal with ways you cope with the stress in your life. There are many ways to try to deal with problems. These items ask what you do to cope with stress. Obviously, different people deal with things in different ways, but I'm interested in how you deal with it. Each item says something about a particular way of coping. I want to know to what extent you do what the item says. How much or how frequently. Don't answer on the basis of whether it works or not—just whether or not you do it. Use these response choices. Try to rate each item separately in your mind from the others. Make your answers as true FOR YOU as you can.

1 = I haven't been doing this at all
2 = I've been doing this a little bit
3 = I've been doing this a medium amount
4 = I've been doing this a lot

___ 1. I turn to work or other activities to take my mind off things.
___ 2. I concentrate my efforts on doing something about the situation I'm in.
___ 3. I say to myself "this isn't real.".
___ 4. I use alcohol or other drugs to make myself feel better.
___ 5. I get emotional support from others.
___ 6. I give up trying to deal with it.
___ 7. I take action to try to make the situation better.
___ 8. I refuse to believe that it has happened.
___ 9. I say things to let my unpleasant feelings escape.
___ 10. I get help and advice from other people.
___ 11. I use alcohol or other drugs to help me get through it.
___ 12. I try to see it in a different light, to make it seem more positive.
___ 13. I criticize myself.
___ 14. I try to come up with a strategy about what to do.
___ 15. I get comfort and understanding from someone.
___ 16. I give up the attempt to cope.
___ 17. I look for something good in what is happening.
___ 18. I make jokes about it.
___ 19. I do something to think about it less, such as going to movies, watching TV, reading, daydreaming, sleeping, or shopping.
___ 20. I accept the reality of the fact that it has happened.
___ 21. I express my negative feelings.
___ 22. I try to find comfort in my religion or spiritual beliefs.
___ 23. I try to get advice or help from other people about what to do.
___ 24. I learn to live with it.
___ 25. I think hard about what steps to take.
___ 26. I blame myself for things that happened.
___ 27. I pray or meditate.
___ 28. I make fun of the situation.

Dispositional Flow Scale

Please fill in the activity you feel most engaged in and then answer the following questions in relation to your experience of your chosen activity. These questions relate to the thoughts and feelings you may experience during participation in your activity. You may experience these characteristics some of the time, all of the time, or none of the time. There are no right or wrong answers. Think about how often you experience each characteristic during your activity, then circle, or insert in the "Score" box, the number that best matches your experience.

What is the activity you most feel engaged in? __________________________________

Score		When participating in your FLOW activity	Never	Rarely	Sometimes	Frequently	Often
	1	I am challenged, but I believe my skills will allow me to meet the challenge	1	2	3	4	5
	2	I make the correct movements without thinking about trying to do so	1	2	3	4	5
	3	I know clearly what I want to do	1	2	3	4	5
	4	It is really clear to me how my performance is going	1	2	3	4	5
	5	My attention is focused entirely on what I am doing	1	2	3	4	5
	6	I have a sense of control over what I am doing	1	2	3	4	5
	7	I am not concerned with what others may be thinking of me	1	2	3	4	5
	8	Time seems to alter (either slows down or speeds up)	1	2	3	4	5
	9	I really enjoy the experience	1	2	3	4	5
	10	My abilities match the high challenge of the situation	1	2	3	4	5
	11	Things just seem to happen automatically	1	2	3	4	5
	12	I have a strong sense of what I want to do	1	2	3	4	5
	13	I am aware of how well I am performing	1	2	3	4	5
	14	It is no effort to keep my mind on what is happening	1	2	3	4	5
	15	I feel like I can control what I am doing	1	2	3	4	5
	16	I am not concerned with how others may be evaluating me	1	2	3	4	5
	17	The way time passes seems to be different from normal	1	2	3	4	5
	18	I love the feeling of the performance and want to capture it again	1	2	3	4	5
	19	I feel I am competent enough to meet the high demands of the situation	1	2	3	4	5
	20	I perform automatically, without thinking too much	1	2	3	4	5

	21	I know what I want to achieve	1	2	3	4	5
	22	I have a good idea while I am performing about how well I am doing	1	2	3	4	5
	23	I have total concentration	1	2	3	4	5
	24	I have a feeling of total control	1	2	3	4	5
	25	I am not concerned with how I am presenting myself	1	2	3	4	5
	26	It feels like time goes by quickly	1	2	3	4	5
	27	The experience leaves me feeling great	1	2	3	4	5
	28	The challenge and my skills are at an equally high level	1	2	3	4	5
	29	I do things spontaneously and automatically without having to think	1	2	3	4	5
	30	My goals are clearly defined	1	2	3	4	5
	31	I can tell by the way I am performing how well I am doing	1	2	3	4	5
	32	I am completely focused on the task at hand	1	2	3	4	5
	33	I feel in total control of my body	1	2	3	4	5
	34	I am not worried about what others may be thinking of me	1	2	3	4	5
	35	I lose my normal awareness of time	1	2	3	4	5
	36	The experience is extremely rewarding	1	2	3	4	5

Types of Intuition Scale (TIntS)

We are interested in how you make decisions and solve problems in your life. Read each of the following statements and rate the extent to which you would agree that that statement is true of you using the scale below. These items have no right or wrong answers; just respond based on what is true for you. Write the number corresponding to your response on the line before each statement.

1	2	3	4	5
Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree

__ 1. I usually make a better decision if I sleep on it first.
__ 2. I've had enough experience to just know what I need to do most of the time without trying to figure it out every time.
__ 3. I tend to use my heart as a guide for my actions.
__4. After working on a problem for a long time, I like to set it aside for a while before making a final decision.
__ 5. My approach to problem solving relies heavily on my past experience.
__ 6. I generally don't depend on my feelings to help me make decisions.
__ 7. When working on a problem, I prefer to work slowly so that there is time for all the pieces to come together.
__ 8. When I have much experience or knowledge about a problem, I almost always trust my intuitions.
__ 9. I think it is foolish to make important decisions based on feelings.
__ 10. Ambiguity makes me very uncomfortable.
__ 11. When I have little experience with a problem, I prefer not to trust my intuition.
__ 12. When making decisions, I value my feelings and hunches just as much as I value facts.
__ 13. When I get stuck working on a problem, the answer frequently comes to me suddenly at some later point in time.
__ 14. My instincts in my areas of expertise are much better than in areas I do not know well.
__ 15. I prefer to follow my head rather than my heart.
__ 16. I am not very good at keeping in mind the big picture when working on a problem.
__ 17. My intuitive judgments are based on a few key pieces of information.
__ 18. Rather than spend my time trying to think of how to deal with a problem situation, I prefer to use my emotional hunches.
__ 19. I enjoy thinking in abstract terms.
__ 20. When I analyze my problems, I tend to miss important information and make a worse decision than if I had trusted my intuition.
__ 21. If I have to, I can usually give reasons for my intuitions.
__ 22. I often make decisions based on my gut feelings, even when the decision is contrary to objective information.
__ 23. I would rather think in terms of theories than facts.

__ 24. I rely on my intuition when I have little experience or knowledge about a problem.
__ 25. My intuitions come to me very quickly.
__ 26. I like to rely on my intuitive impressions.
__ 27. When I have a specific plan for solving a problem, I always stick to it and do not allow myself to get distracted.
__ 28. When I trust my intuition, I come to the same conclusion as if I had carefully analyzed the situation.
__ 29. I believe in trusting my hunches.
__ 30. Even after I have a specific plan for solving a problem, I make an effort to remain open to other approaches.
__ 31. In a familiar area, I am comfortable making a decision based on limited information when I have to.
__ 32. I rarely allow my emotional reactions to override logic.
__ 33. When making decisions, I try to suspend my assumptions and prior beliefs.
__ 34. I am more likely to trust my intuition on complex problems than simpler ones.
__ 35. There is a logical justification for most of my intuitive judgments.
__ 36. I almost always trust my intuition because I think it is a bad idea to analyse everything.
__ 37. Intuition is an accurate and reliable shortcut for problems that would otherwise require a lot of analysis.

SWINBURNE UNIVERSITY OF TECHNOLOGY

INFORMED CONSENT

PROJECT TITLE:

Investigating brain activity associated with flow states during video game play

INVESTIGATORS:

Assoc. Prof Joseph Ciorciari, Senior Lecturer (Swinburne University of Technology), Joshua Gold (Swinburne University of Technology - School of the Brain & Psychological Sciences)

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

In relation to this project, please circle your response to the following:

- I agree to be interviewed by the researcher **Yes** **No**
- I agree to allow the interview to be recorded by electronic device **Yes** **No**
- I agree to make myself available for further information if required **Yes** **No**
- I agree to complete questionnaires asking me about

  [Absorption, Need for Cognition, COPE, Intuition, Mindfulness and Life Satisfaction] **Yes**

  No

3. I acknowledge that:

   (a) my participation is voluntary and that I am free to withdraw from the project at any time without explanation;

   (b) the Swinburne project is for the purpose of research and not for profit;

   (c) any identifiable information about me which is gathered in the course of and as the result of my participating in this project will be (i) collected and retained for the purpose of this project and (ii) accessed and analysed by the researcher(s) for the purpose of conducting this project;

   (d) my anonymity is preserved and I will not be identified in publications or otherwise without my express written consent.

By signing this document you agree to participate in this project.
As you will be undergoing EEG analysis certain information pertaining to your medical history is required to be obtained for your safety.

Please indicate to the researcher if any of the following are relevant to you. However, it is not necessary to indicate any specifics, as these questions are only for screening purposes.

▪ Do you have history of any Psychiatric or Neurological Condition?	**Yes**	**No**
▪ Do you suffer from Epilepsy?	**Yes**	**No**
▪ Is there a history of Epilepsy in your family?	**Yes**	**No**
▪ Have you ever suffered from convulsions?	**Yes**	**No**
▪ Do you suffer from a medical condition that requires medication?	**Yes**	**No**
▪ Do you have a history of head trauma?	**Yes**	**No**
▪ Do you have a history of claustrophobia?	**Yes**	**No**

In giving consent, the participant states that they do not have or not aware of having the aforementioned medical concerns.

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

Name of Participant:
……………………………………………………………………………

Signature & Date: ……………………………………………………………

* NAME OF AUTHORISED REPRESENTATIVE: Joshua Gold
POSITION: Researcher ....
SIGNATURE...DATE...................

NAME/S OF PRINCIPAL INVESTIGATOR/S: Dr Joseph Ciorciari, Joshua Gold
SIGNATURE.. **DATE**........................
SIGNATURE.. **DATE**........................
SIGNATURE.. **DATE**........................
SIGNATURE.. **DATE**........................
SIGNATURE.. **DATE**........................

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human*

Research. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.

Experimental forms during both trials

Inter-Game Flow Scale

Think about how you felt during the game, and then answer the questions using the rating scale below. For each question, mark on the line where it best matches your experience.

	Not at All		Completely
I was 'in the zone'	I-----I-----I-----I-----I-----I-----I-----I-----I-----I-----I		
It felt like 'everything clicked'	I-----I-----I-----I-----I-----I-----I-----I-----I-----I-----I		
It felt like 'nothing else mattered'	I-----I-----I-----I-----I-----I-----I-----I-----I-----I-----I		
I'd love to play the game again	I-----I-----I-----I-----I-----I-----I-----I-----I-----I-----I		
To what degree did the demands of the game match your ability?	I-----I-----I-----I-----I-----I-----I-----I-----I-----I-----I		

	Very Short		Very Long
Estimate the length of time you spent playing the game	I-----I-----I-----I-----I-----I-----I-----I-----I-----I-----I		

Sensation Check

Please describe the physical sensations you are feeling from the stimulation using the list of 10 descriptors below:

0) no sensation,

1) cold,

2) some tingling,

3) warm,

4) lots of tingling/some itching,

5) very warm,

6) lots of itching,

7) burning (like a sunburn),

8) burning (like scalding water)

9) "hurts a lot".

Appendix 4: Self report questionnaire (Publication 3)

SWINBURNE UNIVERSITY OF TECHNOLOGY

Behavioural Measures

PROJECT TITLE
Investigating brain activity associated with flow states during video game play
INVESTIGATORS
Dr. Joseph Ciorciari, Senior Lecturer (Swinburne University of Technology), Joshua Gold (Swinburne University of Technology - School of the Brain & Psychological Sciences)

All data collected from you will remain entirely confidential, as a code will be attached to your data and no name will accompany any information you will supply. Your anonymous data will only ever be accessed by the investigators mentioned above. Results of this study may be published in a peer reviewed journal or presented at conferences.

Any questions regarding the project entitled < Investigating brain activity associated with flow states during video game play > can be directed to the Senior Investigators Dr. Joseph Ciorciari of the Department/School of the Brain & Psychological Sciences Research Centre on telephone number <9214-8363 >.

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact:
Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.

Tellegen Absorption Scale

This questionnaire consists of questions about experiences that you may have had in your life. We are interested in how often you have these experiences. It is important, however, that your answers show how often these experiences happen to you when you are not under the influence of alcohol or drugs.

1	2	3	4	5
extremely uncharacteristic of me	somewhat uncharacteristic of me	uncertain	somewhat characteristic of me	extremely characteristic of me

______ 1. Sometimes I feel and experience things as I did when I was a child.
______ 2. I can be greatly moved by eloquent or poetic language.
______ 3. While watching a movie, a TV show, or a play, I may sometimes become so involved that I forget about myself and my surroundings and experience the story as if it were real and as if I were taking part in it.
______ 4.If I stare at a picture and then look away from it, I can sometimes 'see' an image of the picture, almost as if I were still looking at it.
______ 5. Sometimes I feel as if my mind could envelop the whole earth.
______ 6. I like to watch cloud shapes in the sky.
______ 7. If I wish, I can imagine (or daydream) some things so vividly that they hold my attention as a good movie or a story does.
______ 8. I think I really know what some people mean when they talk about mystical experiences.
______ 9. I sometimes 'step outside' my usual self and experience an entirely different state of being.
______ 10. Textures-such as wool, sand, wood-sometimes remind me of colours or music.
______ 11. Sometimes I experience things as if they were doubly real.
______ 12. When I listen to music, I can get so caught up in it that I don't notice anything else.
______ 13. If I wish, I can imagine that my whole body is so heavy that I could not move it if I wanted to.
______ 14. I can often somehow sense the presence of another person before I actually see or hear him/her.
______ 15. The crackle and flames of a wood fire stimulates my imagination.
______ 16. It is sometimes possible for me to be completely immersed in nature or art and to feel as if my whole state of consciousness has somehow been temporarily altered.
______ 17. Different colours have distinctive and special meanings for me.
______ 18. I am able to wander off into my own thought while doing a routine task and actually forget that I am doing the task, and then find a few minutes later that I have completed it.
______ 19. I can sometimes recollect certain past experiences in my life with such clarity and vividness that it is like living them again or almost so.
______ 20. Things that might seem meaningless to others often make sense to me.
______ 21. While acting in a play, I think I would really feel the emotions of the character and "become" her/him for the time being, forgetting both myself and the audience.
______ 22. My thoughts often do not occur as words but as visual images.
______ 23. I often take delight in small things (like the five pointed star shape that appears when you cut an apple across the core or the colours in soap bubbles).
______ 24. When listening to organ music or other powerful music, I sometimes feel as if I am being lifted into the air.

_______ 25. Sometimes I can change noise into music by the way I listen to it.
_______ 26. Some of my most vivid memories are called up by scents and smells.
_______ 27. Certain pieces of music remind me of pictures or moving patterns of colour.
_______ 28. I often know what someone is going to say before he or she says it.
_______ 29. I often have “physical memories” for example, after I have been swimming I may still feel as if I am in the water
_______ 30. The sound of a voice can be so fascinating to me that I can just go on listening to it.
_______ 31. At times I somehow feel the presence of someone who is not physically there.
_______ 32. Sometimes thoughts and images come to me without the slightest effort on my part.
_______ 33. I find that different odors have different colours.
_______ 34. I can be deeply moved by a sunset.

Need for Cognition Scale

For each of the statements below, please indicate whether or not the statement is characteristic of you or of what you believe. For example, if the statement is extremely uncharacteristic of you or of what you believe about yourself (not at all like you) please place a "1" on the line to the left of the statement. If the statement is extremely characteristic of you or of what you believe about yourself (very much like you) please place a "5" on the line to the left of the statement. You should use the following scale as you rate each of the statements below.

1	2	3	4	5
extremely uncharacteristic of me	somewhat uncharacteristic of me	uncertain	somewhat characteristic of me	extremely characteristic of me

1. ____ I really enjoy a task that involves coming up with new solutions to problems.
2. ____ I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
3. ____ I tend to set goals that can be accomplished only by expending considerable mental effort
4. ____ I am usually tempted to put more thought into a task than the job minimally requires.
5. ____ Learning new ways to think doesn't excite me very much.
6. ____ I am hesitant about making important decisions after thinking about them.
7. ____ I usually end up deliberating about issues even when they do not affect me personally.
8. ____ I prefer to just let things happen rather than try to understand why they turned out that way.
9. ____ I have difficulty thinking in new and unfamiliar situations.
10. ____ The idea of relying on thought to make my way to the top does not appeal to me.
11. ____ The notion of thinking abstractly is not appealing to me.
12. ____ I am an intellectual
13. ____ I only think as hard as I have to.
14. ____ I don't reason well under pressure.
15. ____ I like tasks that require little thought once I've learned them.
16. ____ I prefer to think about small, daily projects to long-term ones.
17. ____ I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
18. ____ I find little satisfaction in deliberating hard and for long hours.
19. ____ I more often talk with other people about the reasons for and possible solutions to international problems than about gossip or tidbits of what famous people are doing.
20. ____ These days, I see little chance for performing well, even in "intellectual" jobs, unless one knows the right people.
21. ____ More often than not, more thinking just leads to more errors.
22. ____ I don't like to have the responsibility of handling a situation that requires a lot of thinking.
23. ____ I appreciate opportunities to discover the strengths and weaknesses of my own reasoning.
24. ____ I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
25. ____ Thinking is not my idea of fun.
26. ____ I try to anticipate and avoid situations where there is a likely chance I will have to think in depth about something.
27. ____ I prefer watching educational to entertainment programs.

28. ____I think best when those around me are very intelligent.
29.____ I prefer my life to be filled with puzzles that I must solve.
30.____ I would prefer complex to simple problems.
31.____ Simply knowing the answer rather than understanding the reasons for the answer to a problem is fine with me.
32.____ It's enough for me that something gets the job done, I don't care how or why it works.
33.____ Ignorance is bliss.
34.____ I enjoy thinking about an issue even when the results of my thought will have no effect on the outcome of the issue.

Five Facet Mindfulness Questionnaire

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

_____ 1. When I'm walking, I deliberately notice the sensations of my body moving.
_____ 2. I'm good at finding words to describe my feelings.
_____ 3. I criticize myself for having irrational or inappropriate emotions.
_____ 4. I perceive my feelings and emotions without having to react to them.
_____ 5. When I do things, my mind wanders off and I'm easily distracted.
_____ 6. When I take a shower or bath, I stay alert to the sensations of water on my body.
_____ 7. I can easily put my beliefs, opinions, and expectations into words.
_____ 8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.
_____ 9. I watch my feelings without getting lost in them.
_____ 10. I tell myself I shouldn't be feeling the way I'm feeling.
_____ 11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.
_____ 12. It's hard for me to find the words to describe what I'm thinking.
_____ 13. I am easily distracted.
_____ 14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.
_____ 15. I pay attention to sensations, such as the wind in my hair or sun on my face.
_____ 16. I have trouble thinking of the right words to express how I feel about things
_____ 17. I make judgments about whether my thoughts are good or bad.
_____ 18. I find it difficult to stay focused on what's happening in the present.
_____ 19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.
_____ 20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.
_____ 21. In difficult situations, I can pause without immediately reacting.
_____ 22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.
_____ 23. It seems I am "running on automatic" without much awareness of what I'm doing.
_____ 24. When I have distressing thoughts or images, I feel calm soon after.
_____ 25. I tell myself that I shouldn't be thinking the way I'm thinking.
_____ 26. I notice the smells and aromas of things.
_____ 27. Even when I'm feeling terribly upset, I can find a way to put it into words.
_____ 28. I rush through activities without being really attentive to them.
_____ 29. When I have distressing thoughts or images I am able just to notice them without reacting.
_____ 30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.
_____ 31. I notice visual elements in art or nature, such as colours, shapes, textures, or patterns of light and shadow.
_____ 32. My natural tendency is to put my experiences into words.
_____ 33. When I have distressing thoughts or images, I just notice them and let them go.

_____ 34. I do jobs or tasks automatically without being aware of what I'm doing.
_____ 35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.
_____ 36. I pay attention to how my emotions affect my thoughts and behaviour.
_____ 37. I can usually describe how I feel at the moment in considerable detail.
_____ 38. I find myself doing things without paying attention.
_____ 39. I disapprove of myself when I have irrational ideas.

Flourishing Scale

Below are 8 statements with which you may agree or disagree. Using the 1–7 scale below, indicate your agreement with each item by indicating that response for each statement.

- _7 – Strongly agree
- _6 – Agree
- _5 – Slightly agree
- _4 – Neither agree nor disagree
- _3 – Slightly disagree
- _2 – Disagree
- _1 – Strongly disagree

____ I lead a purposeful and meaningful life
____ My social relationships are supportive and rewarding
____ I am engaged and interested in my daily activities
____ I actively contribute to the happiness and well-being of others
____ I am competent and capable in the activities that are important to me
____ I am a good person and live a good life
____ I am optimistic about my future
_____ People respect me

Scale of Positive and Negative Experience

Please think about what you have been doing and experiencing during the past four weeks. Then report how much you experienced each of the following feelings, using the scale below. For each item, select a number from 1 to 5, and indicate that number on your response sheet.

1. Very Rarely or Never
2. Rarely
3. Sometimes
4. Often
5. Very Often or Always

Positive ______________________
Negative ______________________
Good ______________________
Bad ______________________
Pleasant ______________________
Unpleasant ______________________
Happy ______________________
Sad ______________________
Afraid ______________________
Joyful ______________________
Angry ______________________

Contented ________________________

Satisfaction with Life Scale

Below are five statements that you may agree or disagree with. Using the 1 - 7 scale below, indicate your agreement with each item by placing the appropriate number on the line preceding that item. Please be open and honest in your responding.

- 7 - Strongly agree
- 6 - Agree
- 5 - Slightly agree
- 4 - Neither agree nor disagree
- 3 - Slightly disagree
- 2 - Disagree
- 1 - Strongly disagree

____ In most ways my life is close to my ideal.

____ The conditions of my life are excellent.

____ I am satisfied with my life.

____ So far I have gotten the important things I want in life.

____ If I could live my life over, I would change almost nothing.

Brief COPE

These items deal with ways you cope with the stress in your life. There are many ways to try to deal with problems. These items ask what you do to cope with stress. Obviously, different people deal with things in different ways, but I'm interested in how you deal with it. Each item says something about a particular way of coping. I want to know to what extent you do what the item says. How much or how frequently. Don't answer on the basis of whether it works or not—just whether or not you do it. Use these response choices. Try to rate each item separately in your mind from the others. Make your answers as true FOR YOU as you can.

1 = I haven't been doing this at all
2 = I've been doing this a little bit
3 = I've been doing this a medium amount
4 = I've been doing this a lot

___ 1. I turn to work or other activities to take my mind off things.
___ 2. I concentrate my efforts on doing something about the situation I'm in.
___ 3. I say to myself "this isn't real.".
___ 4. I use alcohol or other drugs to make myself feel better.
___ 5. I get emotional support from others.
___ 6. I give up trying to deal with it.
___ 7. I take action to try to make the situation better.
___ 8. I refuse to believe that it has happened.
___ 9. I say things to let my unpleasant feelings escape.
___ 10. I get help and advice from other people.
___ 11. I use alcohol or other drugs to help me get through it.
___ 12. I try to see it in a different light, to make it seem more positive.
___ 13. I criticize myself.
___ 14. I try to come up with a strategy about what to do.
___ 15. I get comfort and understanding from someone.
___ 16. I give up the attempt to cope.
___ 17. I look for something good in what is happening.
___ 18. I make jokes about it.
___ 19. I do something to think about it less, such as going to movies, watching TV, reading, daydreaming, sleeping, or shopping.
___ 20. I accept the reality of the fact that it has happened.
___ 21. I express my negative feelings.
___ 22. I try to find comfort in my religion or spiritual beliefs.
___ 23. I try to get advice or help from other people about what to do.
___ 24. I learn to live with it.
___ 25. I think hard about what steps to take.
___ 26. I blame myself for things that happened.
___ 27. I pray or meditate.
___ 28. I make fun of the situation.

Types of Intuition Scale (TIntS)

We are interested in how you make decisions and solve problems in your life. Read each of the following statements and rate the extent to which you would agree that that statement is true of you using the scale below. These items have no right or wrong answers; just respond based on what is true for you. Write the number corresponding to your response on the line before each statement.

1	2	3	4	5
Definitely False	Mostly False	Undecided *Neither True Nor False*	Mostly True	Definitely True

_____ 1. When tackling a new project, I concentrate on big ideas rather than the details.

_____ 2. I trust my intuitions, especially in familiar situations.

_____ 3. I prefer to use my emotional hunches to deal with a problem, rather than thinking about it.

_____ 4. Familiar problems can often be solved intuitively.

_____ 5. There is a logical justification for most of my intuitive judgments.

_____ 6. I rarely allow my emotional reactions to override logic.

_____ 7. I tend to use my heart as a guide for my actions.

_____ 8. My intuitions come to me very quickly.

_____ 9. I would rather think in terms of theories than facts.

_____ 10. My intuitions are based on my experience.

_____ 11. I often make decisions based on my gut feelings, even when the decision is contrary to objective information.

_____ 12. When working on a complex problem or decision I tend to focus on the details and lose sight of the big picture.

_____ 13. I believe in trusting my hunches.

_____ 14. I prefer concrete facts over abstract theories.

_____ 15. When making a quick decision in my area of expertise, I can justify the decision logically.

_____ 16. I generally don't depend on my feelings to help me make decisions.

_____ 17. If I have to, I can usually give reasons for my intuitions.

_____ 18. I prefer to follow my head rather than my heart.

_____ 19. I enjoy thinking in abstract terms.

_____ 20. I try to keep in mind the big picture when working on a complex problem.

_____ 21. When I make intuitive decisions, I can usually explain the logic behind my decision.

_____ 22. It is foolish to base important decisions on feelings.

_____ 23. I am a 'big picture' person.

Dispositional Flow Scale

Please fill in the activity you feel most engaged in and then answer the following questions in relation to your experience of your chosen activity. These questions relate to the thoughts and feelings you may experience during participation in your activity. You may experience these characteristics some of the time, all of the time, or none of the time. There are no right or wrong answers. Think about how often you experience each characteristic during your activity, then circle, or insert in the "Score" box, the number that best matches your experience.

What is the activity you most feel engaged in? ____________________________________

Score		When participating in your FLOW activity	Never	Rarely	Sometimes	Frequently	Often
	1	I am challenged, but I believe my skills will allow me to meet the challenge	1	2	3	4	5
	2	I make the correct movements without thinking about trying to do so	1	2	3	4	5
	3	I know clearly what I want to do	1	2	3	4	5
	4	It is really clear to me how my performance is going	1	2	3	4	5
	5	My attention is focused entirely on what I am doing	1	2	3	4	5
	6	I have a sense of control over what I am doing	1	2	3	4	5
	7	I am not concerned with what others may be thinking of me	1	2	3	4	5
	8	Time seems to alter (either slows down or speeds up)	1	2	3	4	5
	9	I really enjoy the experience	1	2	3	4	5
	10	My abilities match the high challenge of the situation	1	2	3	4	5
	11	Things just seem to happen automatically	1	2	3	4	5
	12	I have a strong sense of what I want to do	1	2	3	4	5
	13	I am aware of how well I am performing	1	2	3	4	5
	14	It is no effort to keep my mind on what is happening	1	2	3	4	5
	15	I feel like I can control what I am doing	1	2	3	4	5
	16	I am not concerned with how others may be evaluating me	1	2	3	4	5
	17	The way time passes seems to be different from normal	1	2	3	4	5
	18	I love the feeling of the performance and want to capture it again	1	2	3	4	5
	19	I feel I am competent enough to meet the high demands of the situation	1	2	3	4	5

	20	I perform automatically, without thinking too much	1	2	3	4	5
	21	I know what I want to achieve	1	2	3	4	5
	22	I have a good idea while I am performing about how well I am doing	1	2	3	4	5
	23	I have total concentration	1	2	3	4	5
	24	I have a feeling of total control	1	2	3	4	5
	25	I am not concerned with how I am presenting myself	1	2	3	4	5
	26	It feels like time goes by quickly	1	2	3	4	5
	27	The experience leaves me feeling great	1	2	3	4	5
	28	The challenge and my skills are at an equally high level	1	2	3	4	5
	29	I do things spontaneously and automatically without having to think	1	2	3	4	5
	30	My goals are clearly defined	1	2	3	4	5
	31	I can tell by the way I am performing how well I am doing	1	2	3	4	5
	32	I am completely focused on the task at hand	1	2	3	4	5
	33	I feel in total control of my body	1	2	3	4	5
	34	I am not worried about what others may be thinking of me	1	2	3	4	5
	35	I lose my normal awareness of time	1	2	3	4	5
	36	The experience is extremely rewarding	1	2	3	4	5

General Questions

What is your age?

What is your sex?

Are you left or right handed?

How many hours a week do you play video games?

What are the most common video games you play?

How would you rate your proficiency at video games?

1 – Don’t know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

How would you rate your proficiency at first person shooter video games?

1 – Don’t know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

How would you rate your proficiency at Tetris?

1 – Don’t know how to play
2 – Not Good
3 – Good
4 – Competitive
5 – Professional

Appendix 5: Ethics clearance

Dear Joe

SHR Project 2014/310 Investigating brain activity associated with flow states during video game play and the effects of neuro-modulation technology as an inductive method
Assoc Prof Joseph Ciorciari, Mr Joshua Gold (Student), Assoc Prof Christine Critchley - FHAD
Approved Duration: 18-09-2015 to 30-09-2017 [Adjusted]

I refer to the ethical review of the above project protocol undertaken by Swinburne's Human Research Ethics Committee (SUHREC. Your responses to the review as emailed on 28 July and 3 September 2015 were put to SUHREC delegate(s) for consideration and feedback sent to you. Your response emailed today with attachment accords with the delegate's most recent feedback.

I am pleased to advise that Swinburne approval has now been given for the commencement of the above project in line with the following approval conditions:

1. All human research activity proceeding under Swinburne auspices must conform to Swinburne and external regulatory standards, including the *National Statement on Ethical Conduct in Human Research (2007)* and with respect to secure data use, retention and disposal.
2. The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.
3. Swinburne's Occupational Health & Safety Office requirements re adverse and serious adverse incident reporting must be adhered to.
4. Operational responsibility for timely lodgement and payment of applicable charges for, and compliance with, the CTN Scheme lies with the Swinburne chief investigator and research institute where Swinburne is the CTN sponsor of the trial. This responsibility includes timely reporting of all serious and unexpected adverse reactions to the TGA.
5. Copies of relevant communications with external parties monitoring the ethical and safe conduct of the approved trial should be sent to the Swinburne Research Ethics Office as soon as possible. This includes adverse and serious adverse incident reports, progress and final reports, clinical trial registration, as well as modification requests and approvals. The HREC trial number should be clearly cited in communication.
6. At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring and variations/additions, self-audits and progress reports can be found on the Research Intranet pages.
7. Responsibility for compliance with the terms of ethics clearance remains with the Swinburne chief investigator, including with respect to personnel appointed to or associated with the trial being made aware of the ethics clearance conditions and approved documents.
8. Claims made against the University in respect of the conduct of the approved trial should be communicated as soon as possible to the Swinburne Research Ethics Office and the Swinburne

Finance insurance accountant. Queries concerning currency of insurance and indemnification should similarly be put to the insurance accountant.

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

Please contact me if you have any queries about the Swinburne approval to commence and continue the project, citing the project or trial number. A copy of this approval should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely

Keith

Keith Wilkins
Secretary, SUHREC & Research Ethics Officer
Swinburne Research (H68)
Swinburne University of Technology
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Extension Granted

To: Assoc Prof Joseph Ciorciari, FHAD

Dear Joe

SHR Project 2014/310 Investigating brain activity associated with flow states during video game play and the effects of neuro-modulation technology as an inductive method
Assoc Prof Joseph Ciorciari, Mr Joshua Gold (Student), Assoc Prof Christine Critchley - FHAD
Approved Duration: 18-09-2015 to 30-09-2017 [Adjusted]; extended to 30/12/2017 [September 2016]; extended to 30/06/2018 [September 2017]; extended to 28/02/2019 [June 2018].
Modified: September 2016, September 2017, June 2018.

I refer to the annual report emailed on 27 June 2018 in which you requested an extension of ethics clearance to 28/02/2019.

I am pleased to advise that, as modified to date, the project may continue in line with standard ethics clearance conditions previously communicated and reprinted below. Please note that information on self-auditing, progress/final reporting and modifications/additions to approved protocols can now be found on the Research Ethics Internet pages.

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

As before, best wishes for the project.

Yours sincerely,
Astrid Nordmann

Appendix 6: Experimental code

MEG MaxFilter

```
/neuro/bin/util/x86_64-pc-linux-gnu/maxfilter-2.2 -f
/projects/sinuhe_MEG_data/josh_gold/no_name/151106/joshy_015_adapt1.fif -o
/projects/shared/R039/maxfilter/joshy_015_adapt1_tsss.fif -origin 0 0 40 -frame head -
autobad on -trans default -st 10 -corr .90 -movecomp inter -linefreq 50 -cal
/neuro/databases/sss/sss_cal_3107.dat -ctc /neuro/databases/ctc/ct_sparse.fif -v
```

MEG preprocessing code

```
# -*- coding: utf-8 -*-
"""
Created on Mon Jul 20 11:20:15 2015

@author: joshuagold
"""

#TO DO - Add second stream preprocessing that epochs at ~200ms

import mne
import matplotlib.pylab as plt
import scipy
import numpy as np
import glob
#~ from get_optical_timing import get_optical_timing

#NOTE: Subjs pilot through 6 have split files (2 files per subj), 7 has 3 and the rest (8 -
13) 1.


#Setup paths / subj
rootdir = ''

rawdir = 'Desktop/PhD/MEG/MEG_files/'
#rawdir = rootdir + 'RAW/'
senssave = rootdir + 'sens/'
subj = raw_input('Please enter participant ID:   ')

#8194 = flow check
#4097 = Trial start

#Set up file names to be read in.
subj_slow=glob.glob('/home/is/jgold/Desktop/PhD/MEG/MEG_files/%s*slow*.fif'%subj)
subj_slow=np.sort(subj_slow)
```

```
subj_fast=glob.glob('/home/is/jgold/Desktop/PhD/MEG/MEG_files/%s*fast*.fif'%subj)
subj_fast=np.sort(subj_fast)

subj_adapt=glob.glob('/home/is/jgold/Desktop/PhD/MEG/MEG_files/%s*adapt*.fif'%subj
)
subj_adapt=np.sort(subj_adapt)

#Read in raw data
raw1 = []
raw2 = []
raw3 = []
for idx, lst in enumerate([subj_slow, subj_fast, subj_adapt]):
	for a in lst:

		raw = mne.io.Raw(a, preload = True)
# Adds in lightmeter tigger channels
		d,t = raw[[raw.ch_names.index(x) for x in ['STI102','MISC004']],:]
		if subj == '08':
			d[1,:] *= -1
		div = d[1,:] - d[1,:].mean()	# remove dc
		vth = (div.max()-div.min())/4	# threshold
		div[0] = vth*1.1		# ensure we catch first trigger
		w = (div<vth)
		wf= (w[1:]-w[:-1]).nonzero()[0]
		wf2 = wf[1:]-wf[:-1]
		vlst = [wf[i+1] for i in range(len(wf2)) if wf2[i] > 500]   # assumes stimulus
interval > 500 ms

		new_trig = np.zeros(d.shape[1])
		for i in vlst:
			new_trig[i:i+20] = 1

		raw._data[raw.ch_names.index('STI102'),:] += new_trig

		if idx == 0:
			raw1.append(raw)
		elif idx == 1:
			raw2.append(raw)
		elif idx == 2:
			raw3.append(raw)



#~ raw1=[mne.io.Raw(a, preload = True) for a in subj_slow]
#~ raw2=[mne.io.Raw(b, preload = True) for b in subj_fast]
```

```
#~ raw3=[mne.io.Raw(c, preload = True) for c in subj_adapt]

#Concatinate data pieces together

for x in range(1,len(raw1)):
   raw1[0].append(raw1[x])

for x in range(1,len(raw2)):
   raw2[0].append(raw2[x])

for x in range(1,len(raw3)):
   raw3[0].append(raw3[x])

#Change trigger values for file 1
trigs1=raw1[0]._data[raw1[0].ch_names.index('STI102')]
trigs1[:][trigs1[:] == 2] = 11


#Change trigger values for file 2
trigs2=raw2[0]._data[raw2[0].ch_names.index('STI102')]
trigs2[:][trigs2[:] == 2] = 21


#Change trigger values for file 3
trigs3=raw3[0]._data[raw3[0].ch_names.index('STI102')]
trigs3[:][trigs3[:] == 2] = 31


#Write back altered trigger channels to raw files.
raw1[0]._data[raw1[0].ch_names.index('STI102')] = trigs1
raw2[0]._data[raw2[0].ch_names.index('STI102')] = trigs2
raw3[0]._data[raw3[0].ch_names.index('STI102')] = trigs3

#Append raw files (one at a time as all three together crashes system)
raw1[0].append(raw2[0])
raw1[0].append(raw3[0])

#Select montages

ev=mne.find_events(raw1[0], stim_channel='STI102', output = 'onset');
ev2 = ev
ev2[:,0] = ev2[:,0] - 5000
ev2_bak = ev2

hold_array=np.zeros([25,3])
```

```
for x in range(0,len(ev2)):
    hold_array[0] = ev2[x]
    for y in range(1,len(hold_array)):
        hold_array[y,0] = hold_array[y-1,0]+200
        hold_array[y,1] = hold_array[y-1,1]
        hold_array[y,2] = hold_array[y-1,2]
    ev2 = np.concatenate((ev2,hold_array),axis = 0)

raw1[0].resample(250)
raw1[0].filter(l_freq = 1, h_freq = 100, picks=None, filter_length='10s',
l_trans_bandwidth=0.5, h_trans_bandwidth=0.5, method='fft', iir_params=None,
verbose=None, n_jobs = 10)


#ICA cleaning
from mne.preprocessing.ica import ICA
ica = ICA(n_components=0.95, method='fastica').fit(raw1[0], decim=30)

comp_idx = np.arange(ica.n_components_)

ica.plot_components(comp_idx, ch_type = 'mag')
ica.plot_components(comp_idx, ch_type = 'grad')

comp_hold = [input('Enter components to reject (commas separating numbers):   ')]

ica.apply(raw1[0], include = None, exclude = comp_hold)

plt.close('all')

raw1[0].save(rawdir + subj + '_ica_raw_tsss.fif')
```

Occlusion soccer task code (PsychoPy)

```
#!/usr/bin/env python2
# -*- coding: utf-8 -*-
"""
This experiment was created using PsychoPy2 Experiment Builder (v1.83.00rc1), Thu
Oct 15 13:56:19 2015
If you publish work using this script please cite the relevant PsychoPy publications
  Peirce, JW (2007) PsychoPy - Psychophysics software in Python. Journal of
Neuroscience Methods, 162(1-2), 8-13.
  Peirce, JW (2009) Generating stimuli for neuroscience using PsychoPy. Frontiers in
Neuroinformatics, 2:10. doi: 10.3389/neuro.11.010.2008
"""
```

```
from __future__ import division  # so that 1/3=0.333 instead of 1/3=0
from psychopy import locale_setup, visual, core, data, event, logging, sound, gui
from psychopy.constants import *  # things like STARTED, FINISHED
import numpy as np  # whole numpy lib is available, prepend 'np.'
from numpy import sin, cos, tan, log, log10, pi, average, sqrt, std, deg2rad, rad2deg,
linspace, asarray
from numpy.random import random, randint, normal, shuffle
import os  # handy system and path functions
import sys # to get file system encoding

# Ensure that relative paths start from the same directory as this script
_thisDir =
os.path.dirname(os.path.abspath(__file__)).decode(sys.getfilesystemencoding())
os.chdir(_thisDir)

# Store info about the experiment session
expName = 'sports_sim_bug'  # from the Builder filename that created this script
expInfo = {'participant':'', 'session':'001'}
dlg = gui.DlgFromDict(dictionary=expInfo, title=expName)
if dlg.OK == False: core.quit()  # user pressed cancel
expInfo['date'] = data.getDateStr()  # add a simple timestamp
expInfo['expName'] = expName

# Data file name stem = absolute path + name; later add .psyexp, .csv, .log, etc
filename = _thisDir + os.sep + 'data/%s_%s_%s' %(expInfo['participant'], expName,
expInfo['date'])

# An ExperimentHandler isn't essential but helps with data saving
thisExp = data.ExperimentHandler(name=expName, version='',
    extraInfo=expInfo, runtimeInfo=None,
    originPath=None,
    savePickle=True, saveWideText=True,
    dataFileName=filename)
#save a log file for detail verbose info
logFile = logging.LogFile(filename+'.log', level=logging.EXP)
logging.console.setLevel(logging.WARNING)  # this outputs to the screen, not a file

endExpNow = False  # flag for 'escape' or other condition => quit the exp

# Start Code - component code to be run before the window creation

# Setup the Window
win = visual.Window(size=(1680, 1050), fullscr=True, screen=0, allowGUI=False,
allowStencil=False,
    monitor='testMonitor', color=[0,0,0], colorSpace='rgb',
    blendMode='avg', useFBO=True,
```

```
    )
# store frame rate of monitor if we can measure it successfully
expInfo['frameRate']=win.getActualFrameRate()
if expInfo['frameRate']!=None:
    frameDur = 1.0/round(expInfo['frameRate'])
else:
    frameDur = 1.0/60.0 # couldn't get a reliable measure so guess

# Initialize components for Routine "setup"
setupClock = core.Clock()
poz = [.8,-.8]
col_w = [1,1,1]

col_b = [-1,-1,-1]

# Initialize components for Routine "Introduction_2"
Introduction_2Clock = core.Clock()
text_2 = visual.TextStim(win=win, ori=0, name='text_2',
    text='Please watch the soccer player in the video. The Video will stop just before he
kicks the ball. \nAfter the clip finishes please determine whether the ball is being kicked
out to the left of the screen by pressing left arrow, the right of the screen by pressing the
right arrow key or straight towards you (to the bottom middle of the screen) by pressing
the down key.\nBefore each clip you will have a preperation period. Please stare at the
cross and then press any button when you are ready to watch the clip.\n\nWhen you are
ready to start press any key.',    font='Arial',
    pos=[0, 0], height=0.05, wrapWidth=None,
    color='white', colorSpace='rgb', opacity=1,
    depth=0.0)
polygon_black3 = visual.Rect(win=win, name='polygon_black3',
    width=[0.5, 0.5][0], height=[0.5, 0.5][1],
    ori=0, pos=poz,
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=col_b, fillColorSpace='rgb',
    opacity=1,depth=-2.0,
interpolate=True)

# Initialize components for Routine "Introduction"
IntroductionClock = core.Clock()
cross = visual.Rect(win=win, name='cross',
    width=[0.5, 0.5][0], height=[0.5, 0.5][1],
    ori=0, pos=[0, 0],
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=[1,1,1], fillColorSpace='rgb',
    opacity=1,depth=0.0,
interpolate=True)
text_3 = visual.TextStim(win=win, ori=0, name='text_3',
```

```
    text='\n\n\n\n\n\n\n\n\n\nPlease stare at the cross and then press any key to start.',
font='Arial',
    pos=[0, 0], height=0.1, wrapWidth=None,
    color='white', colorSpace='rgb', opacity=1,
    depth=-1.0)
polygon_black2 = visual.Rect(win=win, name='polygon_black2',
    width=[0.5, 0.5][0], height=[0.5, 0.5][1],
    ori=0, pos=poz,
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=col_b, fillColorSpace='rgb',
    opacity=1,depth=-3.0,
interpolate=True)

# Initialize components for Routine "trial"
trialClock = core.Clock()
ISI = core.StaticPeriod(win=win, screenHz=expInfo['frameRate'], name='ISI')
pretest = visual.MovieStim(win=win, name='pretest',
    filename=u'stim1.mov',
    ori=0, pos=[0, 0], opacity=1,
    depth=-1.0,
    )
polygon_black1 = visual.Rect(win=win, name='polygon_black1',
    width=[0.5, 0.5][0], height=[0.5, 0.5][1],
    ori=0, pos=poz,
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=col_b, fillColorSpace='rgb',
    opacity=1,depth=-2.0,
interpolate=True)

# Initialize components for Routine "response"
responseClock = core.Clock()
text = visual.TextStim(win=win, ori=0, name='text',
    text=u'Press left, down or right arrow',    font=u'Arial',
    pos=[0, 0], height=0.1, wrapWidth=None,
    color=u'white', colorSpace='rgb', opacity=1,
    depth=0.0)
polygon_black = visual.Rect(win=win, name='polygon_black',
    width=[0.5, 0.5][0], height=[0.5, 0.5][1],
    ori=0, pos=poz,
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=col_b, fillColorSpace='rgb',
    opacity=1,depth=-2.0,
interpolate=True)
polygon_white = visual.Rect(win=win, name='polygon_white',
    width=[0.4, 0.4][0], height=[0.4, 0.4][1],
    ori=0, pos=poz,
```

```
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=col_w, fillColorSpace='rgb',
    opacity=1,depth=-3.0,
interpolate=True)

# Initialize components for Routine "Complete"
CompleteClock = core.Clock()
text_4 = visual.TextStim(win=win, ori=0, name='text_4',
    text='Thank you for your great work. \n\nWe will now begin the Tetris component of
the test.',    font='Arial',
    pos=[0, 0], height=0.1, wrapWidth=None,
    color='white', colorSpace='rgb', opacity=1,
    depth=0.0)
polygon_black4 = visual.Rect(win=win, name='polygon_black4',
    width=[0.5, 0.5][0], height=[0.5, 0.5][1],
    ori=0, pos=poz,
    lineWidth=1, lineColor=[1,1,1], lineColorSpace='rgb',
    fillColor=col_b, fillColorSpace='rgb',
    opacity=1,depth=-1.0,
interpolate=True)

# Create some handy timers
globalClock = core.Clock()  # to track the time since experiment started
routineTimer = core.CountdownTimer()  # to track time remaining of each (non-slip)
routine

#------Prepare to start Routine "setup"-------
t = 0
setupClock.reset()  # clock
frameN = -1
# update component parameters for each repeat

# keep track of which components have finished
setupComponents = []
for thisComponent in setupComponents:
    if hasattr(thisComponent, 'status'):
        thisComponent.status = NOT_STARTED

#-------Start Routine "setup"-------
continueRoutine = True
while continueRoutine:
    # get current time
    t = setupClock.getTime()
    frameN = frameN + 1  # number of completed frames (so 0 is the first frame)
    # update/draw components on each frame
```

```
    # check if all components have finished
    if not continueRoutine:  # a component has requested a forced-end of Routine
        break
    continueRoutine = False  # will revert to True if at least one component still running
    for thisComponent in setupComponents:
        if hasattr(thisComponent, "status") and thisComponent.status != FINISHED:
            continueRoutine = True
            break  # at least one component has not yet finished

    # check for quit (the Esc key)
    if endExpNow or event.getKeys(keyList=["escape"]):
        core.quit()

    # refresh the screen
    if continueRoutine:  # don't flip if this routine is over or we'll get a blank screen
        win.flip()

#-------Ending Routine "setup"-------
for thisComponent in setupComponents:
    if hasattr(thisComponent, "setAutoDraw"):
        thisComponent.setAutoDraw(False)

# the Routine "setup" was not non-slip safe, so reset the non-slip timer
routineTimer.reset()

#------Prepare to start Routine "Introduction_2"-------
t = 0
Introduction_2Clock.reset()  # clock
frameN = -1
# update component parameters for each repeat
key_resp_3 = event.BuilderKeyResponse()  # create an object of type KeyResponse
key_resp_3.status = NOT_STARTED
# keep track of which components have finished
Introduction_2Components = []
Introduction_2Components.append(text_2)
Introduction_2Components.append(key_resp_3)
Introduction_2Components.append(polygon_black3)
for thisComponent in Introduction_2Components:
    if hasattr(thisComponent, 'status'):
        thisComponent.status = NOT_STARTED

#-------Start Routine "Introduction_2"-------
continueRoutine = True
while continueRoutine:
    # get current time
```

```
t = Introduction_2Clock.getTime()
frameN = frameN + 1  # number of completed frames (so 0 is the first frame)
# update/draw components on each frame

# *text_2* updates
if t >= 0.0 and text_2.status == NOT_STARTED:
    # keep track of start time/frame for later
    text_2.tStart = t  # underestimates by a little under one frame
    text_2.frameNStart = frameN  # exact frame index
    text_2.setAutoDraw(True)

# *key_resp_3* updates
if t >= 0.0 and key_resp_3.status == NOT_STARTED:
    # keep track of start time/frame for later
    key_resp_3.tStart = t  # underestimates by a little under one frame
    key_resp_3.frameNStart = frameN  # exact frame index
    key_resp_3.status = STARTED
    # keyboard checking is just starting
    win.callOnFlip(key_resp_3.clock.reset)  # t=0 on next screen flip
    event.clearEvents(eventType='keyboard')
if key_resp_3.status == STARTED:
    theseKeys = event.getKeys(keyList=['y', 'n', 'left', 'right', 'space'])

    # check for quit:
    if "escape" in theseKeys:
        endExpNow = True
    if len(theseKeys) > 0:  # at least one key was pressed
        key_resp_3.keys = theseKeys[-1]  # just the last key pressed
        key_resp_3.rt = key_resp_3.clock.getTime()
        # a response ends the routine
        continueRoutine = False

# *polygon_black3* updates
if t >= 0.0 and polygon_black3.status == NOT_STARTED:
    # keep track of start time/frame for later
    polygon_black3.tStart = t  # underestimates by a little under one frame
    polygon_black3.frameNStart = frameN  # exact frame index
    polygon_black3.setAutoDraw(True)

# check if all components have finished
if not continueRoutine:  # a component has requested a forced-end of Routine
    break
continueRoutine = False  # will revert to True if at least one component still running
for thisComponent in Introduction_2Components:
    if hasattr(thisComponent, "status") and thisComponent.status != FINISHED:
        continueRoutine = True
```

```
            break  # at least one component has not yet finished

        # check for quit (the Esc key)
        if endExpNow or event.getKeys(keyList=["escape"]):
            core.quit()

        # refresh the screen
        if continueRoutine:  # don't flip if this routine is over or we'll get a blank screen
            win.flip()

    #-------Ending Routine "Introduction_2"-------
    for thisComponent in Introduction_2Components:
        if hasattr(thisComponent, "setAutoDraw"):
            thisComponent.setAutoDraw(False)
    # check responses
    if key_resp_3.keys in ['', [], None]:  # No response was made
       key_resp_3.keys=None
    # store data for thisExp (ExperimentHandler)
    thisExp.addData('key_resp_3.keys',key_resp_3.keys)
    if key_resp_3.keys != None:  # we had a response
        thisExp.addData('key_resp_3.rt', key_resp_3.rt)
    thisExp.nextEntry()
    # the Routine "Introduction_2" was not non-slip safe, so reset the non-slip timer
    routineTimer.reset()

    # set up handler to look after randomisation of conditions etc
    trials = data.TrialHandler(nReps=5, method='random',
        extraInfo=expInfo, originPath=None,
        trialList=data.importConditions(u'clips.xlsx'),
        seed=None, name='trials')
    thisExp.addLoop(trials)  # add the loop to the experiment
    thisTrial = trials.trialList[0]  # so we can initialise stimuli with some values
    # abbreviate parameter names if possible (e.g. rgb=thisTrial.rgb)
    if thisTrial != None:
        for paramName in thisTrial.keys():
            exec(paramName + '= thisTrial.' + paramName)

    for thisTrial in trials:
        currentLoop = trials
        # abbreviate parameter names if possible (e.g. rgb = thisTrial.rgb)
        if thisTrial != None:
            for paramName in thisTrial.keys():
                exec(paramName + '= thisTrial.' + paramName)

        #------Prepare to start Routine "Introduction"-------
        t = 0
```

```
IntroductionClock.reset()  # clock
frameN = -1
# update component parameters for each repeat
key_resp_4 = event.BuilderKeyResponse()  # create an object of type KeyResponse
key_resp_4.status = NOT_STARTED
# keep track of which components have finished
IntroductionComponents = []
IntroductionComponents.append(cross)
IntroductionComponents.append(text_3)
IntroductionComponents.append(key_resp_4)
IntroductionComponents.append(polygon_black2)
for thisComponent in IntroductionComponents:
    if hasattr(thisComponent, 'status'):
        thisComponent.status = NOT_STARTED

#-------Start Routine "Introduction"-------
continueRoutine = True
while continueRoutine:
    # get current time
    t = IntroductionClock.getTime()
    frameN = frameN + 1  # number of completed frames (so 0 is the first frame)
    # update/draw components on each frame

    # *cross* updates
    if t >= 0.0 and cross.status == NOT_STARTED:
        # keep track of start time/frame for later
        cross.tStart = t  # underestimates by a little under one frame
        cross.frameNStart = frameN  # exact frame index
        cross.setAutoDraw(True)

    # *text_3* updates
    if t >= 0.0 and text_3.status == NOT_STARTED:
        # keep track of start time/frame for later
        text_3.tStart = t  # underestimates by a little under one frame
        text_3.frameNStart = frameN  # exact frame index
        text_3.setAutoDraw(True)

    # *key_resp_4* updates
    if t >= 0.0 and key_resp_4.status == NOT_STARTED:
        # keep track of start time/frame for later
        key_resp_4.tStart = t  # underestimates by a little under one frame
        key_resp_4.frameNStart = frameN  # exact frame index
        key_resp_4.status = STARTED
        # keyboard checking is just starting
        win.callOnFlip(key_resp_4.clock.reset)  # t=0 on next screen flip
        event.clearEvents(eventType='keyboard')
```

```
    if key_resp_4.status == STARTED:
        theseKeys = event.getKeys(keyList=['y', 'n', 'left', 'right', 'space'])

        # check for quit:
        if "escape" in theseKeys:
            endExpNow = True
        if len(theseKeys) > 0:  # at least one key was pressed
            key_resp_4.keys = theseKeys[-1]  # just the last key pressed
            key_resp_4.rt = key_resp_4.clock.getTime()
            # a response ends the routine
            continueRoutine = False

    # *polygon_black2* updates
    if t >= 0.0 and polygon_black2.status == NOT_STARTED:
        # keep track of start time/frame for later
        polygon_black2.tStart = t  # underestimates by a little under one frame
        polygon_black2.frameNStart = frameN  # exact frame index
        polygon_black2.setAutoDraw(True)

    # check if all components have finished
    if not continueRoutine:  # a component has requested a forced-end of Routine
        break
    continueRoutine = False  # will revert to True if at least one component still running
    for thisComponent in IntroductionComponents:
        if hasattr(thisComponent, "status") and thisComponent.status != FINISHED:
            continueRoutine = True
            break  # at least one component has not yet finished

    # check for quit (the Esc key)
    if endExpNow or event.getKeys(keyList=["escape"]):
        core.quit()

    # refresh the screen
    if continueRoutine:  # don't flip if this routine is over or we'll get a blank screen
        win.flip()

#-------Ending Routine "Introduction"-------
for thisComponent in IntroductionComponents:
    if hasattr(thisComponent, "setAutoDraw"):
        thisComponent.setAutoDraw(False)
# check responses
if key_resp_4.keys in ['', [], None]:  # No response was made
   key_resp_4.keys=None
# store data for trials (TrialHandler)
trials.addData('key_resp_4.keys',key_resp_4.keys)
if key_resp_4.keys != None:  # we had a response
```

```
    trials.addData('key_resp_4.rt', key_resp_4.rt)
# the Routine "Introduction" was not non-slip safe, so reset the non-slip timer
routineTimer.reset()

#------Prepare to start Routine "trial"-------
t = 0
trialClock.reset()  # clock
frameN = -1
# update component parameters for each repeat
# keep track of which components have finished
trialComponents = []
trialComponents.append(ISI)
trialComponents.append(pretest)
trialComponents.append(polygon_black1)
for thisComponent in trialComponents:
    if hasattr(thisComponent, 'status'):
        thisComponent.status = NOT_STARTED

#-------Start Routine "trial"-------
continueRoutine = True
while continueRoutine:
    # get current time
    t = trialClock.getTime()
    frameN = frameN + 1  # number of completed frames (so 0 is the first frame)
    # update/draw components on each frame

    # *pretest* updates
    if t >= 0.0 and pretest.status == NOT_STARTED:
        # keep track of start time/frame for later
        pretest.tStart = t  # underestimates by a little under one frame
        pretest.frameNStart = frameN  # exact frame index
        pretest.setAutoDraw(True)
    if pretest.status == FINISHED:  # force-end the routine
        continueRoutine = False

    # *polygon_black1* updates
    if t >= 0.0 and polygon_black1.status == NOT_STARTED:
        # keep track of start time/frame for later
        polygon_black1.tStart = t  # underestimates by a little under one frame
        polygon_black1.frameNStart = frameN  # exact frame index
        polygon_black1.setAutoDraw(True)
    # *ISI* period
    if t >= 0.0 and ISI.status == NOT_STARTED:
        # keep track of start time/frame for later
        ISI.tStart = t  # underestimates by a little under one frame
        ISI.frameNStart = frameN  # exact frame index
```

```
            ISI.start(0.5)
        elif ISI.status == STARTED: #one frame should pass before updating params and
completing
            ISI.complete() #finish the static period

        # check if all components have finished
        if not continueRoutine:  # a component has requested a forced-end of Routine
            break
        continueRoutine = False  # will revert to True if at least one component still running
        for thisComponent in trialComponents:
            if hasattr(thisComponent, "status") and thisComponent.status != FINISHED:
                continueRoutine = True
                break  # at least one component has not yet finished

        # check for quit (the Esc key)
        if endExpNow or event.getKeys(keyList=["escape"]):
            core.quit()

        # refresh the screen
        if continueRoutine:  # don't flip if this routine is over or we'll get a blank screen
            win.flip()

    #-------Ending Routine "trial"-------
    for thisComponent in trialComponents:
        if hasattr(thisComponent, "setAutoDraw"):
            thisComponent.setAutoDraw(False)
    # the Routine "trial" was not non-slip safe, so reset the non-slip timer
    routineTimer.reset()
    thisExp.nextEntry()

# completed 5 repeats of 'trials'


#------Prepare to start Routine "response"-------
t = 0
responseClock.reset()  # clock
frameN = -1
# update component parameters for each repeat
key_resp_2 = event.BuilderKeyResponse()  # create an object of type KeyResponse
key_resp_2.status = NOT_STARTED
# keep track of which components have finished
responseComponents = []
responseComponents.append(text)
responseComponents.append(key_resp_2)
responseComponents.append(polygon_black)
responseComponents.append(polygon_white)
```

```
for thisComponent in responseComponents:
    if hasattr(thisComponent, 'status'):
        thisComponent.status = NOT_STARTED

#-------Start Routine "response"-------
continueRoutine = True
while continueRoutine:
    # get current time
    t = responseClock.getTime()
    frameN = frameN + 1  # number of completed frames (so 0 is the first frame)
    # update/draw components on each frame

    # *text* updates
    if t >= 0.0 and text.status == NOT_STARTED:
        # keep track of start time/frame for later
        text.tStart = t  # underestimates by a little under one frame
        text.frameNStart = frameN  # exact frame index
        text.setAutoDraw(True)

    # *key_resp_2* updates
    if t >= 0.0 and key_resp_2.status == NOT_STARTED:
        # keep track of start time/frame for later
        key_resp_2.tStart = t  # underestimates by a little under one frame
        key_resp_2.frameNStart = frameN  # exact frame index
        key_resp_2.status = STARTED
        # keyboard checking is just starting
        win.callOnFlip(key_resp_2.clock.reset)  # t=0 on next screen flip
        event.clearEvents(eventType='keyboard')
    if key_resp_2.status == STARTED:
        theseKeys = event.getKeys(keyList=['left', 'right', 'down'])

        # check for quit:
        if "escape" in theseKeys:
            endExpNow = True
        if len(theseKeys) > 0:  # at least one key was pressed
            key_resp_2.keys = theseKeys[-1]  # just the last key pressed
            key_resp_2.rt = key_resp_2.clock.getTime()
            # was this 'correct'?
            if (key_resp_2.keys == str(correct_response)) or (key_resp_2.keys ==
correct_response):
                key_resp_2.corr = 1
            else:
                key_resp_2.corr = 0
            # a response ends the routine
            continueRoutine = False
```

```
    # *polygon_black* updates
    if t >= 0.0 and polygon_black.status == NOT_STARTED:
        # keep track of start time/frame for later
        polygon_black.tStart = t  # underestimates by a little under one frame
        polygon_black.frameNStart = frameN  # exact frame index
        polygon_black.setAutoDraw(True)

    # *polygon_white* updates
    if t >= 0.0 and polygon_white.status == NOT_STARTED:
        # keep track of start time/frame for later
        polygon_white.tStart = t  # underestimates by a little under one frame
        polygon_white.frameNStart = frameN  # exact frame index
        polygon_white.setAutoDraw(True)
    if polygon_white.status == STARTED and t >= (0.0 + (.1-
win.monitorFramePeriod*0.75)): #most of one frame period left
        polygon_white.setAutoDraw(False)

    # check if all components have finished
    if not continueRoutine:  # a component has requested a forced-end of Routine
        break
    continueRoutine = False  # will revert to True if at least one component still running
    for thisComponent in responseComponents:
        if hasattr(thisComponent, "status") and thisComponent.status != FINISHED:
            continueRoutine = True
            break  # at least one component has not yet finished

    # check for quit (the Esc key)
    if endExpNow or event.getKeys(keyList=["escape"]):
        core.quit()

    # refresh the screen
    if continueRoutine:  # don't flip if this routine is over or we'll get a blank screen
        win.flip()

#-------Ending Routine "response"-------
for thisComponent in responseComponents:
    if hasattr(thisComponent, "setAutoDraw"):
        thisComponent.setAutoDraw(False)
# check responses
if key_resp_2.keys in ['', [], None]:  # No response was made
   key_resp_2.keys=None
   # was no response the correct answer?!
   if str(correct_response).lower() == 'none': key_resp_2.corr = 1  # correct non-
response
   else: key_resp_2.corr = 0  # failed to respond (incorrectly)
# store data for thisExp (ExperimentHandler)
```

```
thisExp.addData('key_resp_2.keys',key_resp_2.keys)
thisExp.addData('key_resp_2.corr', key_resp_2.corr)
if key_resp_2.keys != None:  # we had a response
    thisExp.addData('key_resp_2.rt', key_resp_2.rt)
thisExp.nextEntry()
# the Routine "response" was not non-slip safe, so reset the non-slip timer
routineTimer.reset()

#------Prepare to start Routine "Complete"-------
t = 0
CompleteClock.reset()  # clock
frameN = -1
# update component parameters for each repeat
# keep track of which components have finished
CompleteComponents = []
CompleteComponents.append(text_4)
CompleteComponents.append(polygon_black4)
for thisComponent in CompleteComponents:
    if hasattr(thisComponent, 'status'):
        thisComponent.status = NOT_STARTED

#-------Start Routine "Complete"-------
continueRoutine = True
while continueRoutine:
    # get current time
    t = CompleteClock.getTime()
    frameN = frameN + 1  # number of completed frames (so 0 is the first frame)
    # update/draw components on each frame

    # *text_4* updates
    if t >= 0.0 and text_4.status == NOT_STARTED:
        # keep track of start time/frame for later
        text_4.tStart = t  # underestimates by a little under one frame
        text_4.frameNStart = frameN  # exact frame index
        text_4.setAutoDraw(True)
    if text_4.status == STARTED and t >= (0.0 + (1.0-win.monitorFramePeriod*0.75)):
#most of one frame period left
        text_4.setAutoDraw(False)

    # *polygon_black4* updates
    if t >= 0.0 and polygon_black4.status == NOT_STARTED:
        # keep track of start time/frame for later
        polygon_black4.tStart = t  # underestimates by a little under one frame
        polygon_black4.frameNStart = frameN  # exact frame index
        polygon_black4.setAutoDraw(True)
```

```
    # check if all components have finished
    if not continueRoutine:  # a component has requested a forced-end of Routine
        break
    continueRoutine = False  # will revert to True if at least one component still running
    for thisComponent in CompleteComponents:
        if hasattr(thisComponent, "status") and thisComponent.status != FINISHED:
            continueRoutine = True
            break  # at least one component has not yet finished

    # check for quit (the Esc key)
    if endExpNow or event.getKeys(keyList=["escape"]):
        core.quit()

    # refresh the screen
    if continueRoutine:  # don't flip if this routine is over or we'll get a blank screen
        win.flip()

#-------Ending Routine "Complete"-------
for thisComponent in CompleteComponents:
    if hasattr(thisComponent, "setAutoDraw"):
        thisComponent.setAutoDraw(False)
# the Routine "Complete" was not non-slip safe, so reset the non-slip timer
routineTimer.reset()

win.close()
core.quit()
```

<u>Flow TETRIS code built for this experiment</u>

```
/*
 * @(#)Game.java
 *
 * This work is free software; you can redistribute it and/or
 * modify it under the terms of the GNU General Public License as
 * published by the Free Software Foundation; either version 2 of
 * the License, or (at your option) any later version.
 *
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 * but WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
 * GNU General Public License for more details.
 *
 * Copyright (c) 2003 Per Cederberg. All rights reserved.
 */

package net.percederberg.tetris;
```

```java
import java.awt.Button;
import java.awt.Component;
import java.awt.Container;
import java.awt.Dimension;
import java.awt.Font;
import java.awt.Graphics;
import java.awt.GridBagConstraints;
import java.awt.GridBagLayout;
import java.awt.Insets;
import java.awt.Label;
import java.awt.Rectangle;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.awt.event.KeyAdapter;
import java.awt.event.KeyEvent;

/**
 * The Tetris game. This class controls all events in the game and
 * handles all the game logics. The game is started through user
 * interaction with the graphical game component provided by this
 * class.
 *
 * @version  1.2
 * @author   Per Cederberg, per@percederberg.net
 */
public class Game extends Object {



  //JOSH - TWEAK THESE PARAMETERS

  //PLAY MODE 0
  public int playMode0_startLevel = 2;

  //PLAY MODE 1
  public int playMode1_startLevel = 2;
  public int playMode1_numLinesToClearInOrderToAdvance = 5;
  public int playMode1_numUnplacedObjectsInOrderToDescend = 15;

  //PLAY MODE 2
  public int playMode2_startLevel = 8;
  public int playMode2_numLinesToClearInOrderToAdvance = 5;

  //END JOSH
```

```
//play mode 0 = super slow, can't speed up (disable down arrow, disable level up)
//play mode 1 =
// if ... 5 lines or more with 30 or less objects... then increase level
// if ... 3 lines or less with 30 or less objects... then decrease level
//play mode 2 = start fast... five lines increase faster

public int numLinesCleared = 0;
public int numObjects = 0;
public int playMode = 1; //default

/**
 * The main square board. This board is used for the game itself.
 */
private SquareBoard board = null;

/**
 * The preview square board. This board is used to display a
 * preview of the figures.
 */
private SquareBoard previewBoard = new SquareBoard(5, 5);

/**
 * The figures used on both boards. All figures are reutilized in
 * order to avoid creating new objects while the game is running.
 * Special care has to be taken when the preview figure and the
 * current figure refers to the same object.
 */
private Figure[] figures = {
  new Figure(Figure.SQUARE_FIGURE),
  new Figure(Figure.LINE_FIGURE),
  new Figure(Figure.S_FIGURE),
  new Figure(Figure.Z_FIGURE),
  new Figure(Figure.RIGHT_ANGLE_FIGURE),
  new Figure(Figure.LEFT_ANGLE_FIGURE),
  new Figure(Figure.TRIANGLE_FIGURE)
};

/**
 * The graphical game component. This component is created on the
 * first call to getComponent().
 */
private GamePanel component = null;

/**
```

```
 * The thread that runs the game. When this variable is set to
 * null, the game thread will terminate.
 */
private GameThread thread = null;

/**
 * The game level. The level will be increased for every 20 lines
 * removed from the square board.
 */
private int level = 1;

/**
 * The current score. The score is increased for every figure that
 * is possible to place on the main board.
 */
private int score = 0;

public int gameNumber = 1;
/**
 * The current figure. The figure will be updated when
 */
private Figure figure = null;

/**
 * The next figure.
 */
private Figure nextFigure = null;

/**
 * The rotation of the next figure.
 */
private int nextRotation = 0;

/**
 * The figure preview flag. If this flag is set, the figure
 * will be shown in the figure preview board.
 */
private boolean preview = true;

/**
 * The move lock flag. If this flag is set, the current figure
 * cannot be moved. This flag is set when a figure is moved all
 * the way down, and reset when a new figure is displayed.
 */
private boolean moveLock = false;
```

```
/**
 * Creates a new Tetris game. The square board will be given
 * the default size of 10x20.
 */
public Game(int playMode) {
  this(playMode, 10, 20);
}

/**
 * Creates a new Tetris game. The square board will be given
 * the specified size.
 *
 * @param width     the width of the square board (in positions)
 * @param height    the height of the square board (in positions)
 */
public Game(int playMode, int width, int height) {
  this.playMode = playMode;
  board = new SquareBoard(width, height);
  board.setMessage("Press start");
  thread = new GameThread();
}

/**
 * Kills the game running thread and makes necessary clean-up.
 * After calling this method, no further methods in this class
 * should be called. Neither should the component returned
 * earlier be trusted upon.
 */
public void quit() {
  thread = null;
}

/**
 * Returns a new component that draws the game.
 *
 * @return the component that draws the game
 */
public Component getComponent() {
  if (component == null) {
    component = new GamePanel();
  }
  return component;
}

/**
 * Handles a game start event. Both the main and preview square
```

```
 * boards will be reset, and all other game parameters will be
 * reset. Finally the game thread will be launched.
 */
private void handleStart() {
  numObjects = 0;
  numLinesCleared = 0;
  // Reset score and figures
  if (playMode == 0) {
    level = playMode0_startLevel; //2
  } else if (playMode == 1) {
    level = playMode1_startLevel; //3;
  } else if (playMode == 2) {
    level = playMode2_startLevel; //9;
  }
  score = 0;
  figure = null;
  nextFigure = randomFigure();
  nextFigure.rotateRandom();
  nextRotation = nextFigure.getRotation();

  // Reset components
  board.setMessage(null);
  board.clear();
//  previewBoard.clear();
  handleLevelModification();
  handleScoreModification();
  component.button.setLabel("Pause");

  // Start game thread
  thread.reset();
}

/**
 * Handles a game over event. This will stop the game thread,
 * reset all figures and print a game over message.
 */
private void handleGameOver() {

  // Stop game thred
  thread.setPaused(true);

  // Reset figures
  if (figure != null) {
    figure.detach();
  }
  figure = null;
```

```
  if (nextFigure != null) {
    nextFigure.detach();
  }
  nextFigure = null;

  // Handle components
  board.setMessage("Game Over");
  component.button.setLabel("Start");

  System.out.println("\t\ngame number " + gameNumber + ":");
  System.out.println("score = " + score);
  System.out.println("level = " + level);

  gameNumber++;
}

/**
 * Handles a game pause event. This will pause the game thread and
 * print a pause message on the game board.
 */
private void handlePause() {
  thread.setPaused(true);
  board.setMessage("Paused");
  component.button.setLabel("Resume");
}

/**
 * Handles a game resume event. This will resume the game thread
 * and remove any messages on the game board.
 */
private void handleResume() {
  board.setMessage(null);
  component.button.setLabel("Pause");
  thread.setPaused(false);
}

/**
 * Handles a level modification event. This will modify the level
 * label and adjust the thread speed.
 */
private void handleLevelModification() {
  component.levelLabel.setText("Level: " + level);
  thread.adjustSpeed();
}

/**
```

```
 * Handle a score modification event. This will modify the score
 * label.
 */
private void handleScoreModification() {
  component.scoreLabel.setText("Score: " + score);
}

/**
 * Handles a figure start event. This will move the next figure
 * to the current figure position, while also creating a new
 * preview figure. If the figure cannot be introduced onto the
 * game board, a game over event will be launched.
 */
private void handleFigureStart() {
  int  rotation;

  // Move next figure to current
  figure = nextFigure;
  moveLock = false;
  rotation = nextRotation;
  nextFigure = randomFigure();
  nextFigure.rotateRandom();
  nextRotation = nextFigure.getRotation();

  // Handle figure preview
  if (preview) {
  //  previewBoard.clear();
  //  nextFigure.attach(previewBoard, true);
  //  nextFigure.detach();
  }

  // Attach figure to game board
  figure.setRotation(rotation);
  if (!figure.attach(board, false)) {
  //  previewBoard.clear();
  //  figure.attach(previewBoard, true);
  //  figure.detach();
    handleGameOver();
  }
}

/**
 * Handles a figure landed event. This will check that the figure
 * is completely visible, or a game over event will be launched.
 * After this control, any full lines will be removed. If no full
 * lines could be removed, a figure start event is launched
```

```
   * directly.
   */
  private void handleFigureLanded() {

    numObjects++;
    // Check and detach figure
    if (figure.isAllVisible()) {
      score += 10;
      handleScoreModification();
    } else {
      handleGameOver();
      return;
    }

    figure.detach();
    figure = null;

    if (playMode == 0) {
      if (board.hasFullLines()) {
          board.removeFullLines();
      } else {
          handleFigureStart();
      }
      return;
    }

    //playMode 1
    else if (playMode == 1) {
      if (board.hasFullLines()) {

          numLinesCleared += board.removeFullLines();

          //if (numLinesCleared >= 5) {
          if (numLinesCleared >= playMode1_numLinesToClearInOrderToAdvance) {
            level++;
            numObjects = 0;
            numLinesCleared = 0;
            handleLevelModification();
          }
      } else {
          //if (numObjects > 30 && level > 1) {
          if (numObjects > playMode1_numUnplacedObjectsInOrderToDescend && level >
1) {
            level--;
            numObjects = 0;
            numLinesCleared = 0;
```

```
        handleLevelModification();
      }
    }

    handleFigureStart();
    return;
  }

  else if (playMode == 2) {
    if (board.hasFullLines()) {
      numLinesCleared += board.removeFullLines();
      if (numLinesCleared >= playMode2_numLinesToClearInOrderToAdvance) {
        level += 1;
        handleLevelModification();
      }
    }

    handleFigureStart();
    return;
  }
}


/**
 * Handles a timer event. This will normally move the figure down
 * one step, but when a figure has landed or isn't ready other
 * events will be launched. This method is synchronized to avoid
 * race conditions with other asynchronous events (keyboard and
 * mouse).
 */
private synchronized void handleTimer() {
  if (figure == null) {
    handleFigureStart();
  } else if (figure.hasLanded()) {
    handleFigureLanded();
  } else {
    figure.moveDown();
  }
}

/**
 * Handles a button press event. This will launch different events
 * depending on the state of the game, as the button semantics
 * change as the game changes. This method is synchronized to
 * avoid race conditions with other asynchronous events (timer and
 * keyboard).
```

```
   */
  private synchronized void handleButtonPressed() {
    if (nextFigure == null) {
      handleStart();
    } else if (thread.isPaused()) {
      handleResume();
    } else {
      handlePause();
    }
  }

  /**
   * Handles a keyboard event. This will result in different actions
   * being taken, depending on the key pressed. In some cases, other
   * events will be launched. This method is synchronized to avoid
   * race conditions with other asynchronous events (timer and
   * mouse).
   *
   * @param e         the key event
   */
  private synchronized void handleKeyEvent(KeyEvent e) {

    // Handle start, pause and resume
    if (e.getKeyCode() == KeyEvent.VK_P) {
      handleButtonPressed();
      return;
    }

    // Don't proceed if stopped or paused
    if (figure == null || moveLock || thread.isPaused()) {
      return;
    }

    // Handle remaining key events
    switch (e.getKeyCode()) {

      case KeyEvent.VK_LEFT:
        figure.moveLeft();
        break;

      case KeyEvent.VK_RIGHT:
        figure.moveRight();
        break;

      case KeyEvent.VK_DOWN:
        if (playMode == 0) {
```

```
            return;
        }

        figure.moveAllWayDown();
        moveLock = true;

        break;

      case KeyEvent.VK_UP:
      case KeyEvent.VK_SPACE:
        if (e.isControlDown()) {
            figure.rotateRandom();
        } else if (e.isShiftDown()) {
            figure.rotateClockwise();
        } else {
            figure.rotateCounterClockwise();
        }
        break;

      case KeyEvent.VK_S:
        if (level < 9) {
            level++;
            handleLevelModification();
        }
        break;

      case KeyEvent.VK_N:
        preview = !preview;
        if (preview && figure != nextFigure) {
            nextFigure.attach(previewBoard, true);
            nextFigure.detach();
        } else {
            previewBoard.clear();
        }
        break;
    }
  }

  /**
   * Returns a random figure. The figures come from the figures
   * array, and will not be initialized.
   *
   * @return a random figure
   */
  private Figure randomFigure() {
    return figures[(int) (Math.random() * figures.length)];
```

```
}


/**
 * The game time thread. This thread makes sure that the timer
 * events are launched appropriately, making the current figure
 * fall. This thread can be reused across games, but should be set
 * to paused state when no game is running.
 */
private class GameThread extends Thread {

  /**
   * The game pause flag. This flag is set to true while the
   * game should pause.
   */
  private boolean paused = true;

  /**
   * The number of milliseconds to sleep before each automatic
   * move. This number will be lowered as the game progresses.
   */
  private int sleepTime = 500;

  /**
   * Creates a new game thread with default values.
   */
  public GameThread() {
  }

  /**
   * Resets the game thread. This will adjust the speed and
   * start the game thread if not previously started.
   */
  public void reset() {
    adjustSpeed();
    setPaused(false);
    if (!isAlive()) {
      this.start();
    }
  }

  /**
   * Checks if the thread is paused.
   *
   * @return true if the thread is paused, or
   *         false otherwise
```

```
 */
public boolean isPaused() {
  return paused;
}

/**
 * Sets the thread pause flag.
 *
 * @param paused     the new paused flag value
 */
public void setPaused(boolean paused) {
  this.paused = paused;
}

/**
 * Adjusts the game speed according to the current level. The
 * sleeping time is calculated with a function making larger
 * steps initially an smaller as the level increases. A level
 * above ten (10) doesn't have any further effect.
 */
public void adjustSpeed() {
  sleepTime = 4500 / (level + 5) - 250;
  if (sleepTime < 50) {
    sleepTime = 50;
  }
}

/**
 * Runs the game.
 */
public void run() {
  while (thread == this) {
    // Make the time step
    handleTimer();

    // Sleep for some time
    try {
        Thread.sleep(sleepTime);
    } catch (InterruptedException ignore) {
        // Do nothing
    }

    // Sleep if paused
    while (paused && thread == this) {
        try {
          Thread.sleep(1000);
```

```
        } catch (InterruptedException ignore) {
          // Do nothing
        }
      }
    }
  }
}


/**
 * A game panel component. Contains all the game components.
 */
private class GamePanel extends Container {

  /**
   * The component size. If the component has been resized, that
   * will be detected when the paint method executes. If this
   * value is set to null, the component dimensions are unknown.
   */
  private Dimension  size = null;

  /**
   * The score label.
   */
  private Label scoreLabel = new Label("Score: 0");

  /**
   * The level label.
   */
  private Label levelLabel = new Label(""); //Level: 1");
  private Label levelLabel2 = new Label(""); //Level: 1");

  /**
   * The generic button.
   */
  private Button button = new Button("Start");

  /**
   * Creates a new game panel. All the components will
   * also be added to the panel.
   */
  public GamePanel() {
    super();
    initComponents();
  }
```

```
/**
 * Paints the game component. This method is overridden from
 * the default implementation in order to set the correct
 * background color.
 *
 * @param g     the graphics context to use
 */
public void paint(Graphics g) {
  Rectangle  rect = g.getClipBounds();

  if (size == null || !size.equals(getSize())) {
    size = getSize();
    resizeComponents();
  }
  g.setColor(getBackground());
  g.fillRect(rect.x, rect.y, rect.width, rect.height);
  super.paint(g);
}

/**
 * Initializes all the components, and places them in
 * the panel.
 */
private void initComponents() {
  GridBagConstraints  c;

  // Set layout manager and background
  setLayout(new GridBagLayout());
  setBackground(Configuration.getColor("background", "#d4d0c8"));

  // Add game board
  c = new GridBagConstraints();
  c.gridx = 0;
  c.gridy = 0;
  c.gridheight = 4;
  c.weightx = 1.0;
  c.weighty = 1.0;
  c.fill = GridBagConstraints.BOTH;
  this.add(board.getComponent(), c);

  // Add next figure board
  c = new GridBagConstraints();
  c.gridx = 1;
  c.gridy = 0;
  c.weightx = 0.2;
  c.weighty = 0.18;
```

```
c.fill = GridBagConstraints.BOTH;
c.insets = new Insets(15, 15, 0, 15);

levelLabel2.setForeground(Configuration.getColor("label",
        "#000000"));
levelLabel2.setAlignment(Label.CENTER);

this.add(levelLabel2, c);
//this.add(previewBoard.getComponent(), c);
//agf


// Add score label
scoreLabel.setForeground(Configuration.getColor("label",
        "#000000"));
scoreLabel.setAlignment(Label.CENTER);
c = new GridBagConstraints();
c.gridx = 1;
c.gridy = 1;
c.weightx = 0.3;
c.weighty = 0.05;
c.anchor = GridBagConstraints.CENTER;
c.fill = GridBagConstraints.BOTH;
c.insets = new Insets(0, 15, 0, 15);
this.add(scoreLabel, c);

// Add level label
levelLabel.setForeground(Configuration.getColor("label",
        "#000000"));
levelLabel.setAlignment(Label.CENTER);
c = new GridBagConstraints();
c.gridx = 1;
c.gridy = 2;
c.weightx = 0.3;
c.weighty = 0.05;
c.anchor = GridBagConstraints.CENTER;
c.fill = GridBagConstraints.BOTH;
c.insets = new Insets(0, 15, 0, 15);
this.add(levelLabel, c);

// Add generic button
button.setBackground(Configuration.getColor("button", "#d4d0c8"));
c = new GridBagConstraints();
c.gridx = 1;
c.gridy = 3;
c.weightx = 0.3;
```

```
  c.weighty = 1.0;
  c.anchor = GridBagConstraints.NORTH;
  c.fill = GridBagConstraints.HORIZONTAL;
  c.insets = new Insets(15, 15, 15, 15);
  this.add(button, c);

  // Add event handling
  enableEvents(KeyEvent.KEY_EVENT_MASK);
  this.addKeyListener(new KeyAdapter() {
    public void keyPressed(KeyEvent e) {
        handleKeyEvent(e);
    }
  });
  button.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent e) {
        handleButtonPressed();
        component.requestFocus();
    }
  });
}

/**
 * Resizes all the static components, and invalidates the
 * current layout.
 */
private void resizeComponents() {
  Dimension  size = scoreLabel.getSize();
  Font       font;
  int        unitSize;

  // Calculate the unit size
  size = board.getComponent().getSize();
  size.width /= board.getBoardWidth();
  size.height /= board.getBoardHeight();
  if (size.width > size.height) {
    unitSize = size.height;
  } else {
    unitSize = size.width;
  }

  // Adjust font sizes
  font = new Font("SansSerif",
        Font.BOLD,
        3 + (int) (unitSize / 1.8));
  scoreLabel.setFont(font);
  levelLabel.setFont(font);
```

```
      font = new Font("SansSerif",
            Font.PLAIN,
            2 + unitSize / 2);
      button.setFont(font);

      // Invalidate layout
      scoreLabel.invalidate();
      levelLabel.invalidate();
      button.invalidate();
    }
  }
    }
```

Appendix 7: EEG experiment setup

<u>EEG procedural checklist</u>

Pre-prep
1) Equipment
Ensure you have all equipment out and ready to cut down prep times.
Consent forms,15 stapled intergame questionnaires and flow state questionnaire. Place participant number on them
pen or pencil
6 pieces of tape at 4cm (fold ½ cm over) – used for additional leads*
4 pieces of tape at 8cm – used to hold audio and ecg leads*
Ecg clips and silver chloride stickers*
6 short additional shallow round plastic electrodes
abrade gel and cotton buds*
syringe and blunt needle*
SST goggles
Light with extension cord connected through round brass pipe and connected to wall in control room. If not connected, you have to remove all the cords first to be able to fit extension cord plug through brass pipe. Also note light is turned on and you control it from the wall switch it is plugged into in the control room. Note: Sometimes light can be twitchy so the globe needs a little fiddling and twisting if it begins to play up ☺
Video camera and tripod (Set up camera for clone monitor in control room). Note you will find camera and wires in second drawer of cabinet in control room.
4 button numeric response pad
battleground 3 and 4 and counter strike source and global offence
Tissues*
Conductive gel tub*
Blue/ Red tube Headphones and yellow disposable ear buds (ensure new yellow buds are set up. place black piping over clear plastic nib. If nib is missing place piping into tube) *
Note: everything with * is found in/ on the cabinet in recording room.

2) Recording Computer Set up
Turn on recording computer from the box.
CTRL+ALT+DELETE
Username: bsi
Password: Simply press enter (no password)
Click on SCAN icon (neuroscan)
Click on big blue play button (triangle)
Go to file> load setup> Use “MOD” version – “Synamps2 mod Quik-Cap62 for SST”
Go to Acquisition>Impedance (This should bring up a display of 64+ pink channels)
Turn display to face towards the recording room.

3) Gaming Computer setup
Turn black game computer on

Check clone computer in control room. If it doesn’t have counter strike and battlefield on desktop, you may need to set up game computer.
Take the monitor cable plugged into the computer that is marked “stim computer” on the top of the cpu box and plug it into the back of the black game computer. It may need an adapter. to enable to fit into machine.
Take mouse and keyboard usb plugged into “stim computer” and plug into any usb ports on game computer.
Plug earphones into headphone port on front top of game computer

Procedure
1) Welcome
Welcome participant and Explain to participant that we are running a gaming study to have a look at gaming performance in the brain.
Have participant read and sign forms.
Explain intergame questionnaire.
Sit them down in recording room and have them set up and begin playing game.

2) Set up: cap size
Size up participant head size and go to clean up room to get appropriate cap. Ensure cap has all electrodes working. Typically cap will have channels written on a tag that indicates if channels are not working. You can take the cap off.
Give earphones to participant. Ask participant to squash yellow bud into a size so that they can they place it into their ears.

3) Set up: Fill up Syringe
use syringe that fits the dull needle
Suck conductive gel out of tub with syringe (take off needle to fill)
twist needle onto syringe

4) Set up: abrade extra channels
Abrade by rubbing with prep gel on cotton bud
a) behind ear on mastoid bones (both sides)
b) outside of eye on horizontal plane (both sides)
c) above and below left eye
d) on wrist on thumb side near edge (both sides) – ensure you can feel a pulse where you abrade.

5) Set up: set up extra channels
Tape is placed on electrode either parallel to the electrode wire (so that it covers part of the wire) or perpendicular (where it forms a T with the wire).
Fill electrode with conductive gel using syringe. Place back of electrode on tape and place at different locations. ensure wire always faces distally (away from center of body)
a) behind ear on mastoid bones (both sides) - PERPENDICULAR
b) outside of eye on horizontal plane (both sides) - PERPENDICULAR
c) above and below left eye - PARALLEL

d) NOTE: no gel for ECG. Place sticker on thumb side of wrist near edge (both sides) with small tab proximally (facing toward elbow). Clip red clip to distal end tab of sticker. Ensure flat side of clip is against skin. Place 8cm tape PERPENDICULAR 5cm from red tab over forearm.

6) Set up: set up cap
Take earphones out
plug cap into preamp sitting on cabinet. Ensure both sides have clipped in. test by slight pull.
Place cap on (ensure its on even and 10-20) Be wary of additional channel wires
Place chinstrap on
Connect up additional leads into cap leads.
a) right mastoid – M1; left mastoid – M2
b) right horizontal eye – HEOR; left horizontal eye – HEOL
c) above eye – VEOU; Below eye – VEOL
d) ECG leads go into leads at the back of the cap – Left ECG – EKGR; Right ECG – EKGL (Ithink these are switched – so please check later on the feed if PQRS (ECG) wave has a positive peak.
Abrade well and fill up GND and REF electrodes (on Z line) plus CZ.
Check impedance screen: HEO, M1/2 and CZ should have all changed color to at least a dark blue. If color change> continue. If no change> Get a new cap.
Proceed to abrade with the dull needle (interchange direction left- right and up-down) and fill up each of the cap electrodes (try not to fill out of electrode). Use a tissue to clean up for each electrode.

2 methods for filling up cap electrode
1) fill up each electrode – no abrading. Once filled up each one. come back and abrade until black.
2) abrade till you see electrode colour flicker. Then fill up. Do this for each one then come back and finish off abrade.
Note: abrade can be easier if you take off from syringe and simply use dull needle.
Note: You can have up to 6 non usable electrodes but try to ensure that they are not next to each other.

7) Set up: Fixing electrode
If electrode is not changing color at all. Grab the box with a white lead and an “L” shaped adapter at the end (currently in room 408, second drawer of cabinet in recording room). Look at number on cap associated with channel position on screen. Then place the “L” into that electrode and the port into the number array on the preamp that is the same as the number on the cap. Watch to see if this changes the colour of the channel on the screen.

8) Recording: set up
Once all the electrodes are between blue and black (black is best). Let the participant know that you are about to start recording and so they will need to stop playing for a moment and take out the head phones.

Then turn off the screen
Explain to the participant: "I am first going to record you doing some basic eye movements which we use to cater for eye muscle noise in the recordings from your brain" Then "After this we will begin the game. When you see the light flicking on and off, please press Number 1 on the number pad on the right of the mouse as fast as you can. Then fill out the questionnaire. Once you finished filling it out you can start playing again"
Close the door
Turn off the impedance screen by pressing the back "stop" square at the top of the screen. It will ask you a question. Press ok.
Then press the green "play" triangle. Then check the reading. ensure that the ecg peak is facing positive (upward). Look at the channels to see that there are no flat lines. If there are, check the connection of the cap with the pre amp.
If all looks good, press the red "record" circle.
Create a new folder in the "Josh flow 2012" folder with the next participant number. Then open up that folder and label the file "1". Press ok and it will begin to record.
Now ask the participant to pick a point on the black screen and stare at it. Press F1 and have them do this for 20 secs. Now press F2 and ask them to close their eyes. Again get them to do this for 20 secs.
Now ask them to open their eyes. Press F3 and ask them to look to the left of the screen. Then press F4 and ask them to look right. Do the F3 and F4 procedure again.
Now ask them to turn on the screen and to begin playing the game.
Press record on the video recorder that is positioned to record the clone screen of the participants game play.
when the participant begins playing press F6.

9) Recording: game play
Recommended: Set up phone timer to keep track of game play.
Watch game play intently.
Press F10 when participant kills someone
Press F11 when participant dies
If you make a mistake press F7 straight away followed by the correct response.

10) Recording: Intergame questionnaire
Watch for when the participant has a) made around 3-4 kills, b) appears to be in control and immersed in the game, and b) has been playing for more than 3 minutes.
Wait for the player to be in a relatively safe space or just after they have died after great game play then perform the following:
Once the player has reached this target, simultaneously press F5 once and begin to flick the power port off and on connected to the lamp in the room. Do this until you see the player click the response pad.
Then place your hand in front of the camera so I know when you have done the stop.
Wait for them to finish the questionnaire.
mark down what number questionnaire they are up to so that you can keep track
When they re-enter game play, press F6
Then start the timer again.

Repeat this for 6-8 questionnaires depending on your time
Note: Sometimes a player may take up to 8 minutes to get into a high performance state. Try to keep this to a minimum as we are trying to get at least 12 questionnaires filled out.

11) Recording: SST
When you start your last regular light flick and F5. Then press the black “stop” button.
Go to file> load setup> Use normal version that does not have mod “Synamps2 Quik-Cap62 for SST”
Then press the green “play” triangle. Then check the reading. There will be no ecg or EOG in this but check to see that the SST line has little pulses on it. Look at the channels to see that there are no flat lines. If there are, check the connection of the cap with the pre amp.
If all looks good, press the red “record” circle.
Then open up the same participant folder and label the file "SST". Press ok and it will begin to record.
Then flick the switch on the back of the white SST box that sits on top of the 2 large external hard drives on the table under the power points. This will cause the SST goggles to present a flickering light.
Go into the recording room and take the SST goggles from hanging on the wall. Ensure light is flickering.
Place goggles on participants head and adjust Velcro straps so that participant is comfortable and the goggles are sitting comfortably over their eyes.
Then close the door
Tell them to begin and press F6
Continue for 3-5 more times using the same procedures as the “*9) Recording: game play*” and “*10) Recording: Intergame questionnaire*”.

12) Finishing: Flow Questionnaire
Once you have finished 11-15 games
press the black “stop” button.
Stop recording and Turn off the video camera
Go into the room and take off the goggles and headphones (hang them back up on wall) EOG, ECG and mastoid electrodes.
Give the participant the flow state questionnaire to fill out.
Take off the cap and take it with electrodes and syringe (throw needle in bin and empty contents back into conductive gel tub) to clean up room (except for ECG leads – wipe them down with alcohol swabs and place in second drawer of cabinet in recording room).
Fill up sink with warm water and place all contents to soak in sink.
Note: only cap soaks, place connection up above on the first shelf.

13) Finishing: Cleaning participant
Once finished with flow state questionnaire escort participant to cleaning room and offer to wash gel out of hair (ask if they want shampoo/ conditioner).
place participant in chair at basin

Check for warm temp and mild water pressure before you wash.
wash out gel
Towels sit under cupboard opposite entry door
dry their hair
Thank them for their help and escort them out

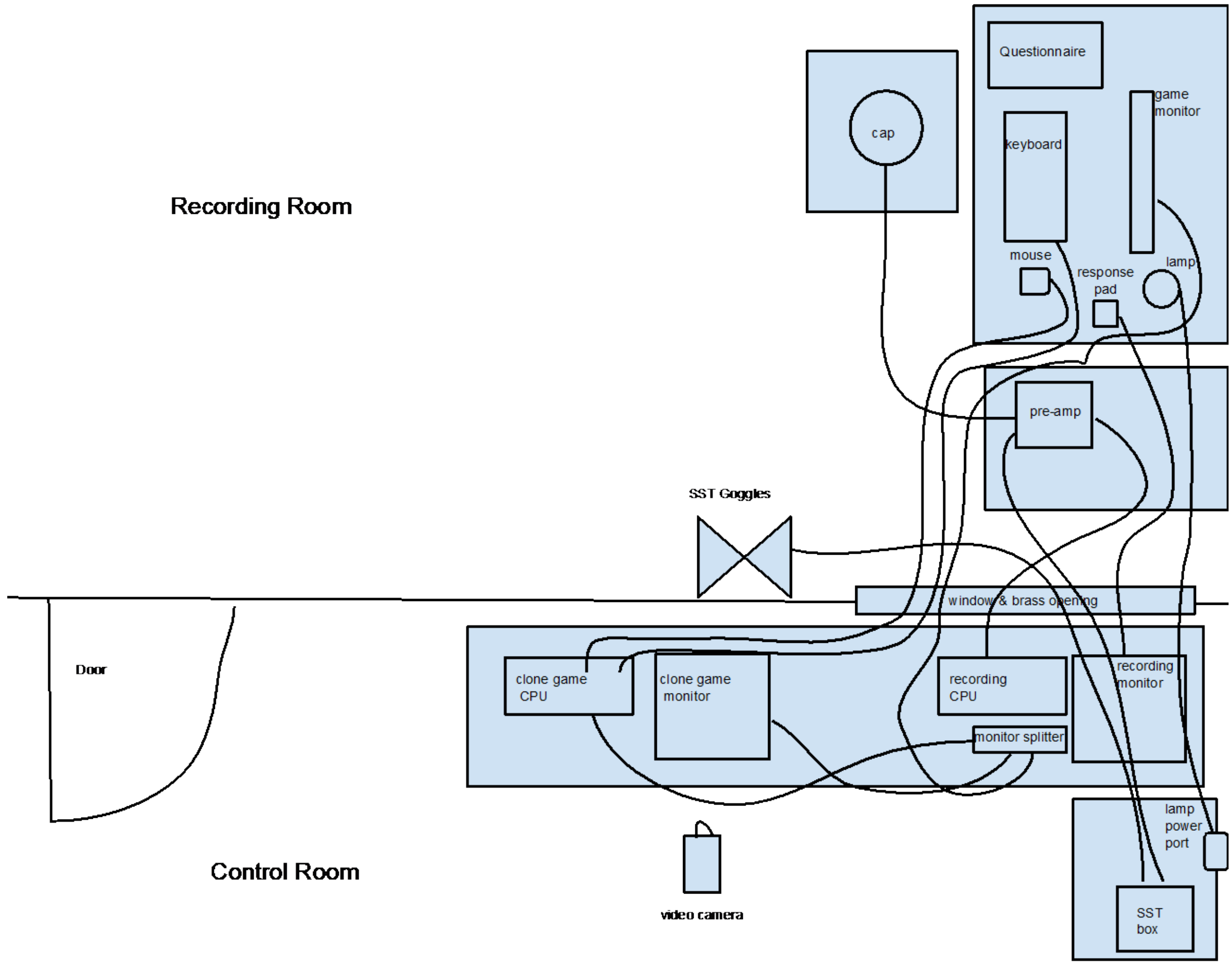
14) Finishing: Cleaning cap
Turn on tap to warm temp and mild water pressure before you wash.
Turn cap inside out
take little wooden stick and swirl around each electrode to help scrape out each electrode then pop through center hole.
Do the say for additional electrodes.
Then rinse with warm water
Take cap and place in pink disinfectant tub. Leave for 3-5 mins.
Swish additional electrodes in disinfectant
Rinse cap and electrodes very well
Place cleaned electrodes, cap and well on dry rack
Fill in details for disinfectant log book.

15) Finishing: Clean up room
Ensure that all rubbish is put in bin
Put tape, cotton buds, electrode stickers, abrading gel, extra needles in top shelf of cabinet.
Turn off recording computer from computer menu.
ensure the monitors are off on the gaming machines

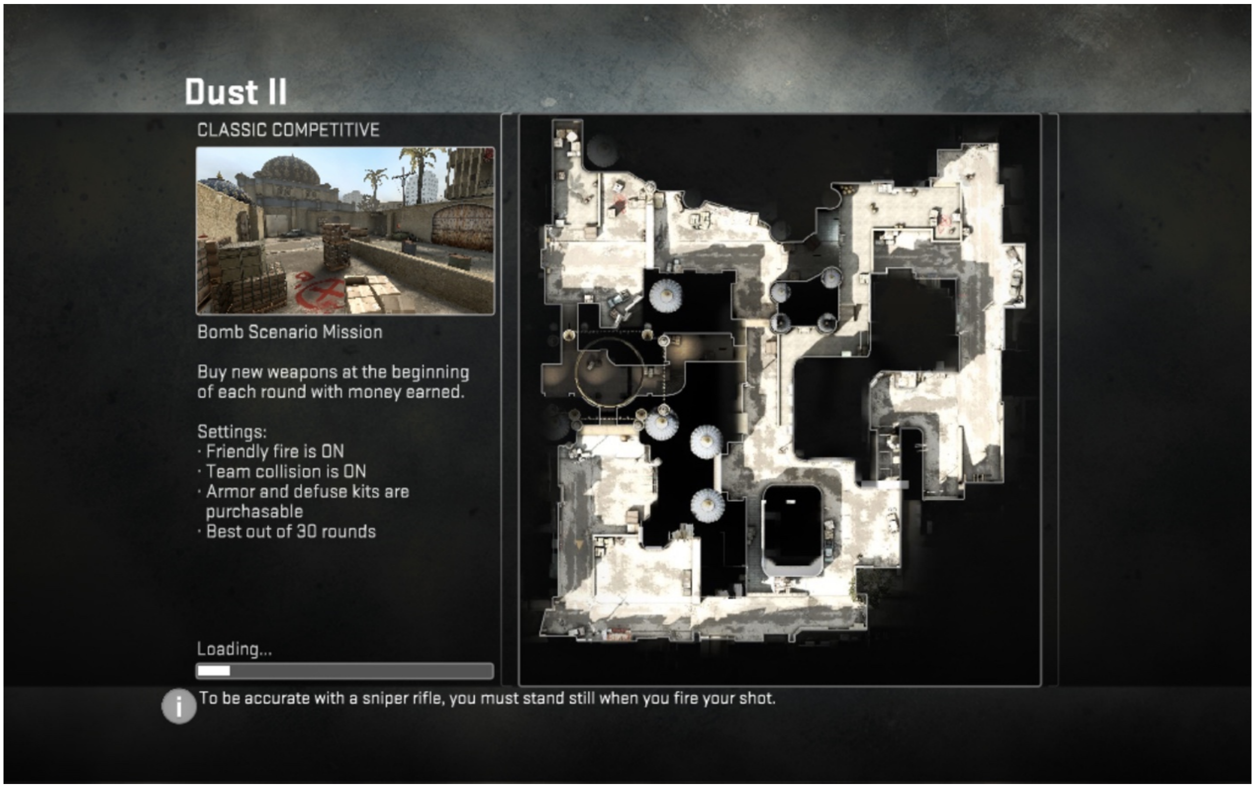
16) Camera
Plug camera into a usb on the recording computer
Plug the camera into a power point
open up screen
press the camera/ play button toggle button.
Then press on the screen computer.
Go to the computer you will find the camera driver
copy and paste the contents of this into the participant folder.
then once you have checked it is in there. Delete from the camera.

Thank you!!!

EEG lab set up diagram

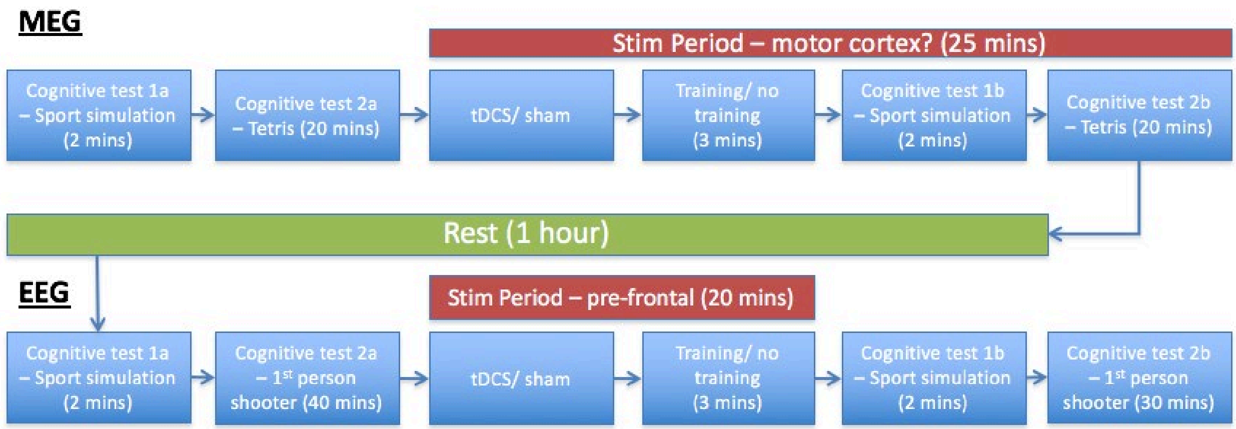


First person shooter game map



TETRIS game play screen with white light marker box

Appendix 8: Study 3 experimental setup



Appendix 9: Experiment Marketing

GETTING YOUR BRAIN IN THE ZONE

You are invited to participate in a PhD study on the neurological patterns of flow states. We also are looking at electrical stimulation technique to help induce flow state. The study aims to investigate brain activity during cognitive/ intellectual testing tasks using video game play. This study aims to provide insights into what is happening in the brain when a person is reaching peak performance experiences. This may provide information relevant to designing more effective educational training and gaming experiences and provide broader understandings about peak experiences to the general research community.

This study requires the participant to first complete 7 basic questionnaires, which will provide basic personal details and relevant personality (Flow Disposition Questionnaire, Absorption, Need for Cognition, COPE, intuition, Mindfulness and Life Satisfaction) traits.

We are using two cognition testing paradigms:

1) Tetris video game

Who we are looking for: Anyone that feels comfortable and reasonably competent playing Tetris.

The actual testing will comprise of two test periods 20 minutes each, in which you will be asked to play the puzzle game Tetris with the Magnetoencephalograph and magnetic resonance imaging (MRI). During the games, the participant will wear a heart monitor. After the first round of game play you will receive a small 2mA electrical DC current applied to the scalp for a period of 25 minutes using an technique called transcranial direct current stimulation (tDCS).

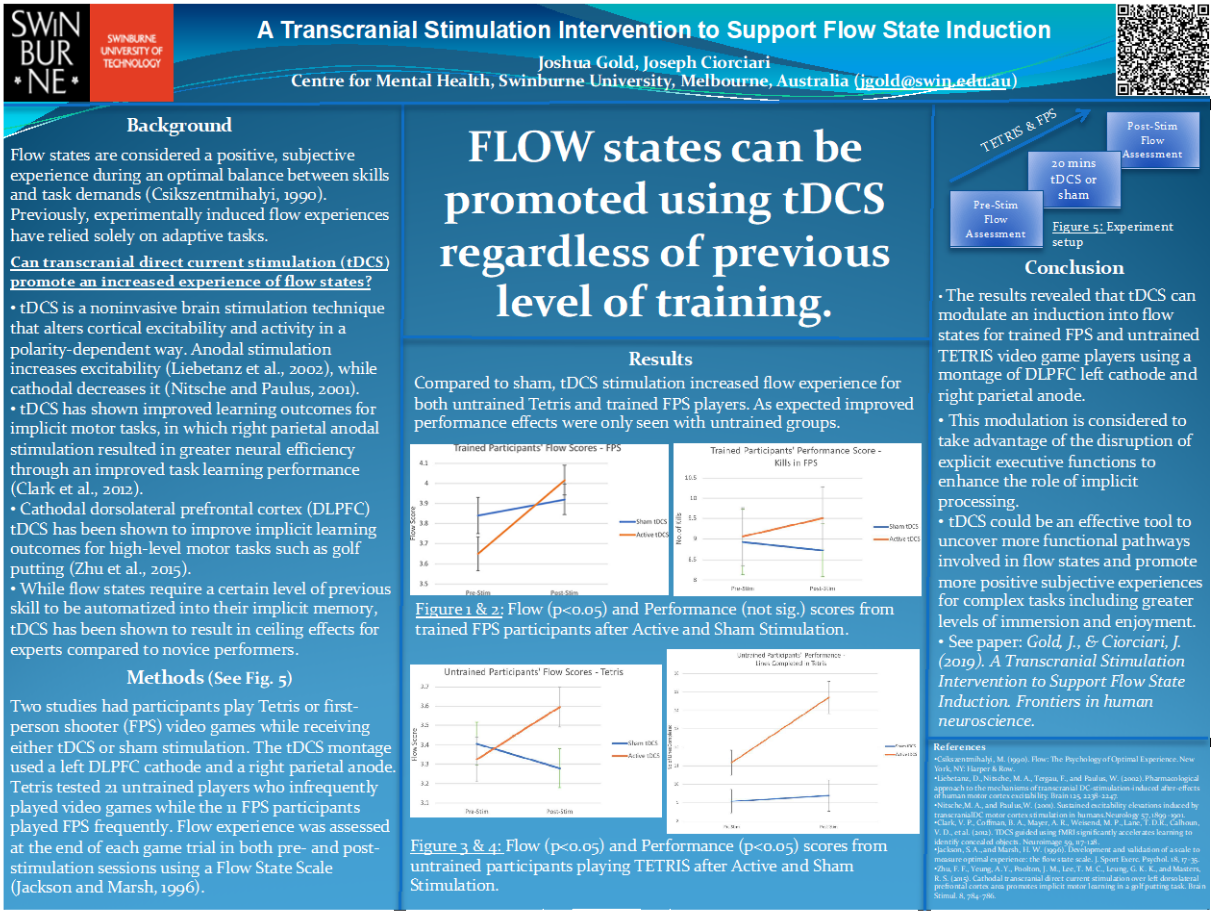
2) First Person Shooter video game

Who we are looking for: Anyone who feels they are a confident player of first person shooters and frequently feels they immerse in the game.

The actual testing will comprise of two test periods 40 minutes each, in which you will be asked to play a multiplayer first person shooter game with the Electroencephalograph. During the games, the participant will wear a heart monitor. After the first round of game play you will receive a small 2mA electrical DC current applied to the scalp for a period of 25 minutes using an technique called transcranial direct current stimulation (tDCS).

You are welcome to participate in any and all parts of the study. If you are interested in doing these flow and personality questionnaires and/ or participating in this study please contact Josh Gold and designate which parts you are interested in doing at jgold@swin.edu.au

Appendix 10: SFN Conference Presentation 2020



Appendix 11: Unused self-report questionnaires

Additionally, other measures were included in the study that were not relevant to the following studies due to their focus on different psychological components. These could be relevant to other studies in follow up studies but did not satisfy the cognitive component that was investigated in this thesis. These measures included a battery of life satisfaction questionnaires consisting of the Flourishing Scale (FS) and Scale of Positive and Negative Experience (SPANE) (E. Diener et al., 2010) as well as the Satisfaction with Life Scale (SWLS) (E. D. Diener, Emmons, Larsen, & Griffin, 1985) which all use Likert scales.

The FS measures agreement with statements about self-perceived success ranging from 1 – Strongly disagree to 7 – strongly agree.

The SPANE measures frequency of experiencing positive and negative feelings ranging from 1 - Very Rarely or Never to 5 - Very Often or Always.

The SWLS measures agreement with global cognitive judgments of satisfaction with one's life success ranging from 1 – Strongly disagree to 7 – strongly agree.

The Types of Intuition Scale (Pretz et al., 2014) was assessed using 23-item scale () and how people make decisions and solve problems in their lives. Participants were asked to indicate on a 5 -point Likert scale ranging from 1 – “Strongly Disagree” to 5 – “Strongly Agree”.

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l region in flow states as it reduces verbal-
analytical involvement in motor control by encouraging limited dependence on working memory