The role of attention control in flow

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signed……………………………………

Abstract

This thesis seeks to examine the state of flow, an experience of complete absorption in the present activity, to understand how changes in attention create this optimal focus. Flow is a somewhat paradoxical state of attention where increasing demands are met with an apparent decrease in effort. Studying this attentional anomaly may be informative for 'normal' attention, and how people may be able to find a peak focus more often. While athletes, artists and people in leisure and workplace settings report flow to be a state of intense concentration, there is very limited understanding of the attentional mechanisms that may be responsible for the state. Indeed, researchers are yet to take overt measures of attentional changes during flow to confirm that attention is indeed more focused.

To address these issues, four studies were conducted to investigate whether the reported focus during flow was related to changes in visual attention across both sporting and computer gaming tasks. Principally these studies aimed to assess whether during flow individuals exhibit strong top-down attention control, and whether this is a key causal mechanism in the state of flow. Studies 1a (Chapter 2) and 2 (Chapter 3)provided initial evidence that flow may be related to trait attention control abilities and improved visual attention control in a sporting task. In a simulated driving task, study 3 (Chapter 4) demonstrated that during flow visual attention was more focused and attentional effort increased, despite relatively low perceived effort. Study 4 (Chapter 5) illustrated how appropriate focusing of attention may be a causal factor in creating flow, suggesting opportunities for training flow through attentional focusing techniques. Overall these studies indicate that attention, in particular the effortful processes of top-down control, may play an important role as a causal mechanism in the state of flow.

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1. Chapter 1

1.1 Introduction

Achieving an optimal mental state for sporting performance allows well-learned skills to be performed without the disruptive effects of distraction, over arousal, self-focus or anxiety (Eysenck & Wilson, 2016). The sporting literature has tended to focus on these disruptive processes, but the study of positive experiential states affords an opportunity to foster peak performance, enjoyment and motivation in sport (Seligman & Csikszentmihalyi, 2014). Flow (Csikszentmihalyi, 1975) is a positive phenomenological state where the individual experiences focused concentration, a merging of action and awareness, a sense of control and a loss of self-consciousness. The sporting environment provides an ideal setting to study flow, as performers are faced with the type of challenges that are facilitative of flow (Engeser & Rheinberg, 2008).

Research in the sporting domain has, to date, utilised mostly qualitative and self-report measures in describing the experience of flow (Jackson, 1995; Swann 2016). Experimental approaches are distinctly lacking, and are required to move beyond a purely descriptive understanding into an examination of the causal mechanisms. While performers in flow describe a state of peak focus (Jackson & Csikszentmihalyi, 1999), this currently remains to be tested using overt measures of attention. Task specific instances of optimal attention control can be used to assess whether individuals reporting flow-like experiences also display changes in visual attention.

Therefore the purpose of this thesis was to investigate changes in visual attention under conditions designed to manipulate flow during visually guided, competitive tasks, in order to assess the role of attention control in flow. The hypotheses of this thesis were (1) that flow would be associated with objective (that is, non-self report) changes in visual attention and (2) that these changes would be indicative of top-down attention control - the biasing of processing towards stimuli in the visuomotor workspace most relevant to current goals

(Knudsen, 2007). This thesis also hoped to develop the experimental method to studying flow in sport that is largely absent from the literature.

The rest of this chapter seeks to provide a review of relevant literature, in two main sections. First, the historical development of the concept of flow and the current state of flow research will be discussed. Secondly, key concepts relating to attention and current research regarding attentional processes during flow will be outlined. Subsequently, methodological issues relating to the measurement of flow and visual attention will be addressed.

Chapters 2-5 outline four experimental studies that address the hypotheses of the thesis. Chapter 2 (Studies 1a and 1b) examines the relationship between trait attention abilities and flow, and state visual attention (quiet eye) and flow in a basketball task. Chapter 3 (Study 2) develops this methodology to further examine quiet eye and flow in basketball and netball shooting. Chapter 4 (Study 3) uses several measures of visual attention pertinent to performance in a driving task to assess whether flow is linked to optimal attention control. Chapter 5 (Study, 4) develops this driving paradigm to evaluate whether a manipulation of attentional focus has a causal influence on flow occurrence. The final chapter (6) brings together the findings of these studies and discusses the theoretical and practical implications for future research in this field.

1.2 Review of the literature

Sections of this literature review were published as; Harris, D.J., Vine, S.J. & Wilson, M.R. (2017) Neurocognitive mechanisms of the flow state. In V. Walsh, M. Wilson & B. Parkin (Eds). *Sport and the Brain: The Science of Preparing, Enduring and Winning (Part B), Progress in Brain Research, 234.* Doi:10.1016/bs.pbr.2017.06.012

1.2.1 The flow state

Flow is a state of complete absorption in the present activity, described by Csikszentmihalyi (1996) as ‘‘an almost automatic, effortless, yet highly focused state of consciousness’’ (p. 110). It is a positive phenomenological state where the individual experiences focused concentration, a merging of action and awareness, a sense of control and a loss of self-consciousness (Csikszentmihalyi, 1975). The study of flow is rooted in the positive psychology perspective (Seligman & Csikszentmihalyi, 2014) where well-being is more than an absence of illness and the quality of consciousness is key. The term ‘flow’ originates from the early descriptive work of Csikszentmihalyi (1975) where it was often used by participants to describe the feeling of acting with full involvement when things felt effortless, as though being carried along in a river.

The study of flow[1] emerged from the intrinsic motivation literature (see Deci & Ryan, 1985), when Csikszentmihalyi identified flow in artists - who would lose themselves in their work, disregarding hunger or fatigue to finish a painting, only to lose interest once it was finished - as a special case of intrinsic motivation (Getzels & Csikszentmihalyi, 1976). To study the nature of this experience, Csikszentmihalyi and LeFevre (1989) had participants paged at random intervals during the day, in order to record their current activity, their perception of the task demands and their emotions (known as the experience sampling method). They observed that quality of experience was more dependent upon the relative balance between demands of the activity and skills of the individual, than whether the task was identified as ‘work’ or ‘leisure’. Moreover, the majority of flow experiences were actually recorded during work.

[1] Colloquially and within sport research the term ‘the zone’ is sometimes used, but ‘flow’ is preferred here due to its wider usage.

This strongly informed the concept of flow, as positive experiences seemed to be a result of task engagement rather than whether or not the task could be considered ‘leisure’. The concept of flow is still largely rooted in the work of Csikszentmihalyi but has been applied to sport in particular (Jackson, 1992; 1995), and more recently has informed computer game design (Chen, 2007). In both these areas, the core construct of a challenge-skill balance has been retained, and research from both areas contributes to this thesis.

The study of flow has identified nine key dimensions of the experience, from which Nakamura and Csikszentmihalyi (2002, see also Kawabata & Mallett, 2011) have subsequently identified three as proximal or preconditions for flow, and the remaining six as characteristics of the subjective state. The proximal conditions, necessary for flow to occur, are: (1) a challenge-skill balance - an evaluation that the demands of the activity match with one’s available skills; (2) clear goals - certainty of what one is trying to achieve; and (3) unambiguous feedback - immediate feedback about the effect of one’s actions.

Csikszentmihalyi suggests that these three factors must be present for a flow state to occur, although their presence does not guarantee flow. These factors do not act independently but interact, as goals and feedback determine the perceived balance. If feedback indicates that you are performing well in relation to your goal, it suggests a challenge-skill (C-S) balance, which is arguably the crucial precondition for flow (Kawabata & Mallett, 2011). Studies, however, show mixed results regarding the importance of the C-S balance, with Moneta and Csikszentmihalyi (1999) finding a C-S balance to explain 47% variance in self-reported concentration. However others have found as little as 2-4% variance in emotional experience attributable to C-S balance (Lovoll & Vitterso, 2012; Voelkl, 1990). In a meta-analysis, Fong, Zaleski and Leach (2015) identified a moderate relationship between C-S balance and flow, suggesting it to be a robust contributor among other antecedents.

In the flow model Csikszentmihalyi identifies how flow relates to other mental states, based on the balance between challenges and skills (see figure 1.1). When challenges outweigh skills, anxiety or worry may be felt, but when the reverse is true, boredom or apathy is experienced. Early models depicted a flow channel that included low skill and low challenge, as long as they were in equilibrium (Csikszentmihalyi, 1975), but subsequent approaches have suggested that skills and challenges should be above the individual average for flow to occur (Nakamura & Csikszentmihalyi, 2002). Controlling the C-S balance has been the primary method of experimentally manipulating flow (Keller & Bless, 2008; Fong et al., 2015), reflecting its importance in flow research.

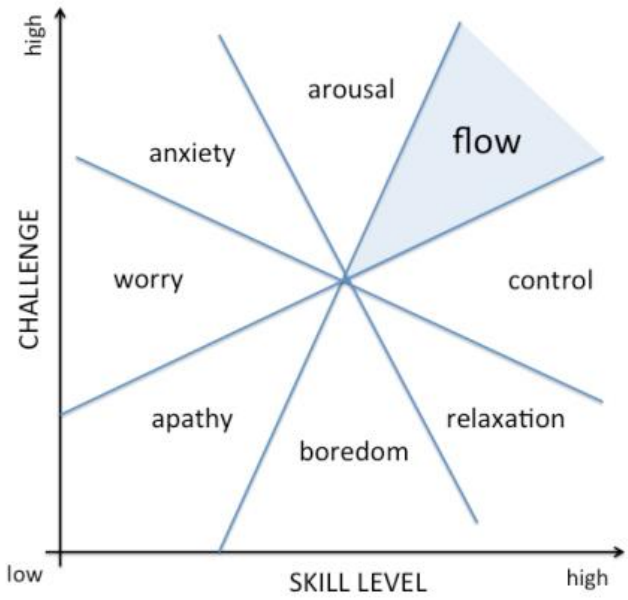

Figure 1.1; the flow model, from '*Flow: The Psychology of Happiness*' (2002)

In addition to the proximal conditions, which could also be described as antecedents, Csikszentmihalyi (1990) identified six factors that characterise the phenomenological experience of being in flow. Crucially the flow experience is defined by its phenomenology, as flow has not occurred without the subjective experience, even if the proximal conditions are met. The six experiential factors are: (1) action-awareness merging - an intense involvement leading to actions feeling spontaneous and automatic; (2) concentration - an intense focus on the present task; (3) sense of control - a feeling that one's actions are effective and can meet task demands; (4) loss of self-consciousness - a reduced awareness of, or concern with, the self; (5) transformation of time - distorted perception of time, which often passes quickly; and (6) autotelicity - experiencing the activity as intrinsically rewarding.

Firstly, action-awareness merging describes how, during flow, movements are automatic and spontaneous. Due to the deep involvement in the task there is no awareness of actions as separate from the self. Athletes in flow often describe their movements as easy, smooth and flowing (Jackson, 1996). This automaticity of movement is described by Jackson and Csikszentmihalyi (1999) as one of the clearest indicators of being in flow.

Secondly, concentration describes how during flow there is a total focus on the activity, while ignoring distracting or painful stimuli. A systematic review by Swann and colleagues (2012) found concentration on the task at hand to be the most commonly reported of the flow dimensions among elite sportspeople. Athletes in flow report that all they were concerned with was the current activity (Swann et al., 2015). Focused concentration may owe much to the optimal challenge that is characteristic of flow, as the situation demands a complete focus in order to meet task demands.

A sense of control refers to feeling capable of exerting an influence on the situation, and in sport in particular, athletes report that they can perform with the assurance that nothing can go wrong (Jackson & Eklund, 2002). The interaction of the proximal conditions for flow are again crucial for a sense of control, as immediate feedback provides an indication that your actions are influencing the situation, and that you are meeting the challenges of the task, leading to a feeling of control.

A loss of self-consciousness describes how concern for the self is reduced during flow, in favour of focusing on the task. The lack of self-consciousness may contribute to the automatic nature of movements and the merging of action and awareness through a reduction in disruptive self-focus. Recent neuroimaging work has provided direct support for this dimension, showing that during flow there is a reduction in activation of medial prefrontal areas linked with self-referential processing (Ulrich et al., 2014; 2016).

Transformation of time refers to the alteration or distortion of the experience of the passage of time (Csikszentmihalyi, 1990). Transformation of time is most commonly experienced as time passing quickly, but can also be experienced as time slowing down. Csikszentmihalyi (1990) acknowledges that this dimension may not be universal, especially during sports where an awareness of time is part of performing well. Time transformation has received more equivocal support in the literature (Jackson, 1992; Swann et al., 2012).

Finally, the description of flow as autotelic refers to an activity being done for its own sake. An autotelic experience is enjoyable and intrinsically rewarding, which occurs as the end result of being in flow. The autotelic experience may be a result of the other dimensions (Csikszentmihalyi, 1990). Athletes in flow report finding enjoyment in their movements, their performance and their effort (Jackson, 1996).

These factors have been used to identify flow regardless of the context; occurring at work (Csikszentmihalyi & LeFevre, 1989; Fullagar & Kelloway, 1999), during sport (Jackson & Csikszentmihalyi, 1999) and in leisure activities (Havitz & Mannell, 2005; Perry, 1999). Studies indicate flow to be experienced similarly across cultures (Fournier et al., 2007; Moneta, 2004; Asakawa, 2010), although the activities in which it is found are culturally relative.

The vast majority of research examining flow is based on Csikszentmihalyi's conceptualization of flow, but within the literature, groups of researchers put varying emphasis on what they see as the core components of the experience. The work of Jackson and colleagues examining flow in sport (Jackson, 1992; 1995; Jackson, Thomas, Marsh & Smethurst, 2001; Jackson & Eklund, 2002) has stayed closely aligned with Csikszentmihalyi's descriptions of flow. In particular, the development and use of questionnaire measures (see section 1.4.1) based on the nine dimensions means this work stays true to the traditional view of flow. Work by Swann and colleagues also strongly uses the 9 dimensions to describe the flow experience, using athletes' descriptions of flow and coding it into Csikszentmihalyi's dimensions (Swann et al., 2012; 2015). This work tends to highlight the positive nature of the flow experience as a crucial component of flow.

Another group of researchers, provide a slightly different perspective on the core aspects of flow, highlighting absorption as the key component. Studies such as Engeser and Rheinberg (2008), Keller et al. (2001), Ulrich, Keller and Gron (2015), Tozman, et al. (2015) and Peifer, et al. (2014) are based on this view of flow which places reduced emphasis on elements like the transformation of time, and the positive nature of the experience. Engeser and Rheinberg (2008) describe how flow experiences are generally autotelic or intrinsically rewarding and enjoyable, but view these aspects as arising from the absorption in the activity. Indeed, the enjoyment of flow often occurs after the experience, as during flow we are too immersed to step back and appreciate the experience (Engeser & Schiepe-Tiska, 2012). Engeser and Rheniberg (2008) and Engeser and Schiepe-Tiska (2012) also suggest flow may occur in activities that are not wholly intrinsically motivated and may not always be positive or 'optimal' (see also Schüler & Brunner, 2009), and as such do not view these as core aspects of flow.

This conceptualization, focusing on task absorption, can be considered a narrower and perhaps reductive view of flow, but reflects the experimental approach of these researchers, and the need for a simple measurement. This is illustrated by the use of the Flow Short Scale (Rheinberg, Vollmeyer & Engeser, 2003, see section 1.4.1) in many of these studies, which focuses on absorption and performance fluency aspects of flow, and omits the intrinsic motivation and positive experiential components. Understanding the subjectively enjoyable aspects of the experience may be possible with more qualitative approaches, but studies such as Tozman, et al. (2015) and Peifer, et al. (2014) attempt to address how variations in flow align with psychophysiological processes. As such the narrower view of flow may reflect this need to simply identify occurrence. As this thesis attempts a similar experimental approach to flow, in line with the studies of Tozman, et al. (2015) and Peifer, et al. (2014), this narrower description of flow is used. Much like these studies the aim of the thesis is to identify when increases/decreases in flow occur under experimental conditions, rather that understand exactly what the experience was like. Therefore, for throughout this thesis, the term 'flow' corresponds to the conceptualization used by these researchers. This is flow as a state of complete absorption and immersion in a challenging activity, and while this may subsequently lead to a positive experience, this is not a core component, as is outlined by Engeser and Rheniberg (2008) and Engeser and Schiepe-Tiska (2012). This does not mean that aspects like intrinsic motivation and enjoyment are not considered part of flow, or that the importance of the holistic experience is disregarded, just that other features such as absorption and performance fluency are more relevant for the current purpose of examining attentional aspects of flow (Engeser & Schiepe-Tiska, 2012).

The autotelic personality

Whilst flow is principally a state variable, individual differences in propensity to attain flow have been described as trait flow, or alternatively the 'autotelic personality' (Csikszentmihalyi, 1990). The autotelic personality refers to individuals who tend to engage in activities for their own sake (Asakawa, 2004), and actively seek challenge. The idea of the autotelic personality is based on the flow model, as autotelic individuals tend to seek, and have the skills to better manage, the balance of high challenge and skill located in the upper right quadrant (Figure 1.1). Csikszentmihalyi suggests personality characteristics such as curiosity, the need to achieve, persistence, openness to novelty and narrow concentration to be important in the seeking and management of challenge (Csikszentmihalyi & Nakamura, 2002). Subsequently research has linked a flow disposition to traditional personality variables neuroticism (negatively), conscientiousness and extraversion (Ullén et al., 2012; Ross & Keiser, 2014).

In the early work of Csikszentmihalyi (1997), experience sampling was used to identify individuals that sought out challenging activities in their daily life. More recently, individual propensity to attain flow has been measured using Jackson and Eklund's (2002) Dispositional Flow Scale, which applies questions from the FSS-2 about a specific activity to more general occurrence. A consideration of the autotelic personality is important for the aims of the thesis in investigating the relationship between flow and attention, as, like flow, attention control has state variation, but also a strong trait component (Friedman et al., 2008). Therefore, attentional abilities may play a role in the autotelic personality, as alluded to by Csikszentmihalyi.

While early work on flow has successfully described what the flow experience is like (Csikszentmihalyi, 1975; Csikszentmihalyi & LeFevre, 1989), there are issues regarding how flow relates to other peak states, and in particular the measurement of flow. These will now be discussed to provide the context for the subsequent outline of research in sport.

1.2.1.1 Conceptual issues

The primary aim of this thesis is to examine attention as a potential causal mechanism in flow, that is, the process or pathway through which flow is brought into being. In particular, the thesis seeks to examine attention as a proximal mechanism, which is a causal event that is closest to or immediately responsible for flow. This is in contrast to distal causes, which occur at a higher level. For instance, much research has identified the importance of the challenge-skill balance in flow (Keller et al., 2011) which seems to play a causal role, but is distal to the experience and is not the *process* which makes flow occur. As changes in attention may be responsible for many of the flow dimensions, such as focused concentration and action-awareness merging, it is a potential proximal cause. Although other proximal causes, such as optimal arousal (Peifer et al., 2014), may also be important. Alternative proximal causal mechanisms that have been proposed for flow include hypofrontality (Dietrich, 2006) and neural synchronisation (Weber, Tamborini, Westcott-Baker & Kantor, 2009) (discussed in section 1.2.1.5) as these also outline neurocognitive pathways.

Proximal causes such as these can be considered distinct from antecedents and conditions in flow research. An antecedent occurs prior to another event, and may cue or make the second event more likely, but is not the process through which the event occurs. Similarly, conditions for flow provide the setting that may make flow more likely. Much research has examined possible antecedents to, and conditions for, flow, such as being focused, feeling positive and prepared, setting goals and feeling confident (Stein, Kimiecik, Daniels & Jackson, 1995; Jackson, 1995). These factors may make flow more likely to occur, but not do not provide a causal mechanism for flow.

While the study of flow in sport addresses the often-neglected personal experience of athletes (Kimiecik & Stein, 1992), it raises a number of issues relating to both the methods used and conceptual clarity. It is imperative to be mindful of these issues to advance this research area. Flow is an experiential state that is distinct from other positive states in sport, like peak experience (Ravizza, 1977) and peak performance (Privette, 1981). While peak experiences are moments of intense joy, they may be passive whereas flow indicates action. For example a peak experience may be joyful because you won, but enjoyment in flow comes from task absorption (Keller & Bless, 2008). Peak performance is also distinct as it is defined by outcome, not subjective experience.

Flow is also related to, but distinct from, the concept of psychological momentum, or 'the hot hand' (see Iso-Ahola & Dotson, 2014 for review). Athletes often report that flow arises from performance (Swann, Keegan, Piggott & Crust, 2012), and that a good initial shot, serve or pass can kick start the flow experience. However, flow may be distinguished from momentum as it is defined by the phenomenological experience, whereas momentum is defined by performance outcomes. Cornelius, Silva, Conroy and Petersen (1997) outline how momentum may be perceived inaccurately by athletes, due to a 'glow' effect. The concept of momentum within their projected performance model is suggested to be due largely to a labeling process in the evaluation of performance. Through a similar process it is possible that the experience of flow (or more specifically, its self-reported occurrence) is a glow effect from good performance. Indeed Brewer, Van Raalte, Linder and Van Raalte (1991) found that non-contingent positive feedback following performance on a rotary pursuit task lead to biased descriptions of the experience as more flow-like. This raises questions about the directionality of the flow to performance relationship (Jackson, Thomas, Marsh and Smethurst, 2001) and illustrates the conceptual difficulty that surrounds concepts like flow and momentum.

Nonetheless, as a mental state defined by its experiential characteristics, the measurement of flow necessarily depends on self-report. As a result, a range of issues arise relating to subjectivity, social desirability and reliability. In particular there may be considerable difficulty in using self-report measurements during a state of absorption. Comparing single and dual task differences, Corallo, Sackur, Dehaene and Sigman (2008) demonstrated how time-on-task estimates are very accurate, until central processing resources are fully consumed, illustrating the difficulty of introspection when highly engaged. The use of flow questionnaires (Jackson & Eklund, 2002; Rheinberg, Vollmeyer & Engeser, 2003) also raises an issue with the unit of time being assessed. The experience of flow is likely to fluctuate moment to moment, but the use of these scales necessitates an averaging over the preceding activity. As a result we may lose information about the complexity of the experience, however interrupting a potential flow experience to ask questions is clearly counterproductive. The early use of experience sampling (Csikszentmihalyi & LeFevre, 1989) suffered from this problem when it attempted to 'catch people in the act', as stopping mid-activity to fill out a questionnaire likely ends any flow that was occurring. An aligned issue with the use of flow questionnaires is how we can identify flow from their usage. Higher scores reflect an experience more representative of flow, but at what point we can claim that flow has occurred is unclear. The inability to clearly identify those experiencing flow from those that are not is certainly a weakness in this research paradigm.

The approach of this thesis is a pragmatic one, as some of these issues present significant problems for flow research, but are not currently solvable. Flow measurement is necessarily dependent upon self-report, which is why newer, direct measurement techniques need to be used alongside traditional measures. The use of this approach within the thesis attempts to address some of the difficulties with the use of purely self-report measurement, and assess whether any objectively measurable (that is, non-self report) changes occur during flow. The importance of the experiential component is acknowledged, but as an understanding of mechanisms and causal factors is needed to develop both theory and practical applications, this will be the focus of the thesis.

1.2.1.2 Flow research in sport

The sport setting is ideally suited for flow research, as sporting activity provides the three conditions Csikszentmihalyi suggests are needed for flow; clear goals, immediate feedback and a balance between challenge and skill. The added effect of physical exertion may further enhance the experience of total absorption (Dietrich, 2006). As there is reasonable agreement over what characterises a flow experience (Swann et al., 2012) research in sport has mainly focused on antecedents of the flow state. For example, Jackson (1992) interviewed elite figure skaters, who identified a positive attitude, appropriate focus and physical readiness - all of which were seen as controllable – as important flow antecedents. Disruptive factors were mistakes, losing focus and lack of audience response. In 1995, Jackson sampled a wider selection of athletes and also identified factors like confidence, focus, preparation and motivation to be important for flow. Interviews have also been used with jockeys (Jackman, Van Hout, Lane & Fitzpatrick, 2014), tennis players (Koehn, 2013) and golfers (Swann, Keegan, Piggott, Crust & Smith, 2012; Swann, Piggott, Crust, Keegan & Hemmings, 2015) to identify antecedents of flow, with factors like confidence, motivation and focus consistently reported as important. State questionnaires are also widely used and have shown flow to be affected by intrinsic motivation (Kowal & Fortier, 1999), background music (Pates, Karageorghis, Fryer & Maynard, 2003) and anxiety (Jackson, Kimiecik, Ford & Marsh, 1998).

More recently Crust and Swann (2013) have investigated the link between mental toughness and flow, finding 45-50% common variance. Swann, Crust, Keegan, Piggott and Hemmings (2014) conducted semi-structured interviews with European Tour golfers, who identified that they knew when they were in flow, and felt able to control it, with most responses fitting into Csikszentmihalyi's 9 dimensions. Koehn (2013) and Stavrou and Zervas (2004) have both identified the beneficial effects of confidence for finding flow, possibly due to its ability to protect against anxiety (Jones & Hanton, 2001), which can disrupt flow (Stavrou & Zervas, 2004).

Swann et al. (2012) conducted a systematic review into the experience and antecedents of flow in elite athletes across 17 studies, finding the most reported aspects of the experience to be concentration and action-awareness merging. They found the most common antecedents to be focus, preparation, motivation, arousal and positive thoughts. These more recent studies use essentially the same methodology as earlier work, either extracting themes from qualitative reports, or finding associations between self-report scales. Sport research can be seen as successful in identifying important factors for setting the conditions for flow but experimental work in the field is limited. Some intervention studies have been conducted which provide a stronger case for the impact of certain factors on flow. For example Pates, Cowen and Karageorghis (2012) used pre-shot routines with three elite golfers, finding improved performance and increased flow experience. Similarly Pates and Cowen (2013) found increases in flow and performance in an elite golfer from a hypnosis intervention and Pain, Harwood and Anderson (2011) utilised imagery and music to similar effect. Intervention studies are important in the development of the flow literature as a key goal is surely to be able to enhance athlete performance through enabling more frequent flow experience, but as the theoretical understanding of the mechanisms behind flow is still developing, interventions cannot make targeted changes to the key causes.

In summary, current sporting research has described the experience and antecedents that may set the scene for flow. In order to move beyond the current understanding alternative methods that take an experimental approach may need to be introduced (Swann, 2016). For example, if the antecedents discussed are genuinely important for flow, controlling these factors should lead to measurable changes. An experimental approach may also be needed to address the relationship between flow and performance.

1.2.1.3 Flow and performance

A key reason why sport psychologists are interested in flow is its relationship with performance; for practical as well as theoretical reasons. If flow enables an optimal mental state, be that through attention, anxiety control or other factors, it is likely to provide performance benefits that can be harnessed. As discussed, these beneficial effects could be due to different mechanisms than effortful sporting performance, where performers ‘make it happen' (Swann et al., 2016). Swann, Crust and Vella (2017) discuss flow and 'clutch' states as overlapping, yet distinct, states of optimal functioning in sport. Clutch performance is a superior performance that occurs under pressure (Otten, 2009) but is distinct from optimal performance in flow (or 'letting it happen', Swann et al., 2016), which is described as more automatic, enjoyable and driven by open goals, as opposed to the deliberate focusing during clutch states (Swann, Crust & Vella, 2017). During flow benefits may come from being relaxed, confident and effortlessly focused (Swann et al., 2016). It may be unreasonable to expect athletes to attain a high level flow state regularly, but it may be possible to achieve a mental state that is more akin to flow, like Csikszentmihalyi's 'micro-flow'. However, the success of this approach relies on demonstrating a causal effect of flow on performance.

Some researchers suggest flow has little cognitive benefit and exerts its effect through enhanced perseverance and engagement (Cseh, Phillips & Pearson, 2015), as intrinsic motivation to keep practicing inevitably enhances general performance. However in the field of sport research there is generally a more positive view of flow's effects, with numerous studies extolling its benefits (Jackson et al., 2001; Bakker, Oerlemans, Demerouti, Slot & Ali, 2011; Koehn, Morris & Watt, 2013; Koehn & Morris, 2014). For example Jackson et al. (2001) found post event flow assessment to show a relationship between flow and good performance. Koehn and Morris (2012) found winning tennis players to score significantly higher on eight of the nine dimensions of the Flow State Scale-2, with predictors 'concentration' and 'sense of control' explaining 13% variance in performance. Alternatively Jackson and Roberts (1992) used questionnaires with collegiate athletes recollecting best performances and found elements of flow occurring during these events. However, perhaps the most convincing findings come from a non-sport study, where flow measures were taken on a statistics task the day before a statistics exam (Engeser & Rheinberg, 2008). It was found that after controlling for other factors (e.g. age and baseline ability) flow explained 4% of the variance in exam performance. Despite similar findings showing a flow-performance link across several studies, the issue remains that flow is not manipulated and as such we cannot be sure about causality. This is not just a methodological concern, as it could be legitimately argued that flow is only the positive experience of performing well, as illustrated by Brewer et al. (1991) in their study using a rotary pursuit task.

Theoretically flow should enable improved performance as it is a highly functional state (Fong, Zaleski & Leach, 2015), but presently it is possible that any relationship between flow and performance is the effect of high performance on the perception of flow. This issue is currently hard to reconcile as the reliance on self-report methods means that performing well may bias the response through a more positive memory of the experience. Indeed Swann et al. (2014) found elite level golfers identified that good initial performance could kick start a flow experience. So conceivably the flow performance link could be in the opposite direction, or something of a virtuous circle. This apparent bi-directional nature of the relationship also raises the question of whether a flow state could be reached during a poor performance. This issue is a result of the correlational approach used, which has been adopted because of the difficulty in manipulating and measuring flow. To assess whether there is a causal relationship, experimental approaches that have been used in gaming may need to be applied to sport research. This thesis aims to use such experimental approaches, and objective measurements of cognitive processes that contribute to optimal performance, in order to further investigate the nature of the flow-performance relationship.

1.2.1.4 Experimental approaches to flow

Experimental approaches in psychology aim to manipulate a factor and measure subsequent outcomes to infer cause and effect relationships. Limited research has addressed flow with experimental designs, possibly due to the inherent difficulties of controlling what can be a fleeting experience (Moller, Meier & Wall, 2010). While important antecedents for flow can be used set up, this doesn't mean flow will occur, so controlling these factors will not necessarily allow an effective manipulation. Those studies that have attempted manipulations have controlled the demands of the task to manipulate the challenge-skill balance, mostly using computer gaming, where the task can be easily controlled and constantly adjusted.

One such approach, developed by Keller and Bless (2008; also Keller, Bless, Blomann & Kleinböhl, 2011) used the game 'Tetris' where falling blocks must be maneuvered into available spaces. The task can be made overly difficult by increasing the speed, so that challenges outweigh skills, leading to the anxiety quadrant in the flow model (see figure 1.1). Alternatively it can be excessively easy, so that skills outweigh challenges, leading to the boredom quadrant. In between, the difficulty can be continually adjusted to match how the participant is performing, creating an optimal balance, providing the conditions for flow (see also Engeser & Rheinberg, 2008). Keller and Bless found that those in the challenge-skill balance condition reported more enjoyment/involvement and had altered perceptions of time passing. Similarly, Tozman, Magdas, MacDougall & Vollmeyer (2015) utilised three levels of track difficulty (easy, hard and matched to skill) to successfully manipulate flow in a driving simulator. Self-ratings of flow were found to be highest in the challenge-skill balance condition, as were ratings of enjoyment. There is, however, some conceptual difficulty with the manipulation of the challenge-skill balance. Firstly, these studies only actually manipulate the challenge, as altering an individual's skill is problematic. Additionally, a perceived balance of challenge and skills is one of the items in most flow questionnaires (e.g. Jackson & Eklund, 2002) creating some circularity in manipulation and measurement. Further, some studies (e.g. Pearce, Ainley & Howard, 2004) have used challenge-skill balance alone as an outcome measure equivalent to flow, putting the cart before the horse. This method of controlling levels of challenge is yet to be used in a sport setting, but the success in gaming would suggest that it may be a useful approach for an experimental investigation of flow. Therefore a similar approach of altering the challenge-skill balance, both through perceived balance and via real alterations of task difficulty, has been used throughout this thesis.

This experimental approach of controlling task difficulty has been used in several studies to examine psychophysiological correlates of flow (deManzano et al., 2010; Peifer et al., 2015; Ulrich et al., 2014;2016). This method has yet to be applied to sport however. Intervention studies (e.g. Pates, Cummings & Maynard, 2002; Pates, Karageorghis, Fryer & Maynard, 2003; Aherne, Moran & Lonsdale, 2011; Pates & Cowen, 2013) provide the closest substitute for experimental work in a sporting setting. Aherne, Moran and Lonsdale (2011) employed a mindfulness intervention among University athletes, finding an increase in self-reported flow. Pates et al. (2003) found 2 out of 3 netball players to report higher flow in the presence of background music and Pates and Cowen (2013) found beneficial effects of a hypnosis intervention for an elite golfer. Unfortunately these studies do not fit a strict definition of 'experimental', as they have limited control over extraneous variables and do not directly control a factor to test cause and effect. Also, they have employed small samples and don't contribute to a mechanistic understanding of flow. As such, there is currently no work in a sporting setting that can be considered truly experimental. Therefore, this thesis aims to take the approach of experimental work outside of sport, principally in the gaming domain, and apply it to sporting tasks.

This approach to experimentally manipulating flow in a lab setting (e.g. Tozman et al., 2015), reflects the need to provide experimental control over the environment to reduce confounding variables and make more reliable inferences about cause and effect. In particular, the use of psychophysiological measurements used in this thesis requires a controlled lab environment. The weakness of this approach is that it does not allow flow to occur in a naturalistic setting, so may not fully equate with athletes' reports of intense flow experiences during competition. In particular, capturing high levels of flow in the lab, where participants are faced with unusual and potentially stressful situations may be difficult. However, Csikszentmihalyi suggests that flow experiences can range from once in a lifetime peak states ('macro flow') to everyday instances of absorption ('micro flow'). This continuum of experiences is important for the study of flow, and the approach of this thesis in particular, as flow experienced in a lab setting may be more akin to micro flow experiences. Nonetheless, if the same experiential elements occur, this allows flow to be studied in a lab setting that allows cause and effect relationships to be more effectively studied, due to greater environmental control.

1.2.1.5 Theories of flow

Scientific theories make explicit, abstract and systematic statements or axioms about the world. They are distinct from data and are explanatory and predictive (Flyvberg, 2001). The pragmatic view of scientific theory acknowledges that theories may also operate at different levels, such as mechanistic, historical and mathematical theories. As such a theory can make predictions at different levels of explanation. Csikszentmihalyi's description of flow outlined above is referred to as a *model*, in that it is a description of how a process works. It could, however, also be considered a theory, in that it outlines distal mechanisms (i.e. the processes through which flow is brought about) such as the challenge-skill balance and is predictive of when flow may occur. It is not, however, a theory of the proximal mechanisms through which flow occurs, such as the neurocognitive or psychophysiological processes that create flow. While theories of flow are perhaps less developed than those in other areas of psychology (eg. anxiety or perception), two theories attempt to explain the proximal mechanisms responsible for flow, through reference to neural mechanisms, and can be complementary to Csikszentmihalyi's more descriptive model.

1.2.1.5.1 Hypofrontality theory

Dietrich (2003) proposed a neural theory of flow that suggests the core components of the experience, and other altered states of consciousness, can be explained by reductions in processing by the prefrontal cortex (PFC). Dietrich suggests that any change to conscious experience should affect the PFC first, as an individual is regarded as functioning on the highest level of consciousness that remains operational (known as phenomenological subtraction). Higher processes like abstract thinking, self-reflective consciousness and working memory are peeled away like an onion, creating states of reduced function in running, meditation or hypnosis. These states are suggested to be linked to flow due to a common mechanism of hypofrontality (i.e. reduced frontal activity and executive functioning). Dietrich (2006) also argues that bodily motion is extremely complex in computational terms, and as such is a considerable drain on mental resources (demonstrated by Dietrich & Sparling, 2004 and Del Giorno, Hall, O'Leary, Bixby & Miller, 2010) which, if prolonged, is sufficient to divert processing away from non-critical processing and brain areas (i.e. higher order function in the PFC). As such Dietrich and Stoll (2010) suggest that many sports are particularly good at engendering flow states. Decreased frontal processing may be harder to justify in activities like computer gaming or creative writing which do not create the drain of complex locomotion.

Imaging studies have provided some support for a reduction in frontal activity, but results suggest a very specific pattern, that does not constitute a general deactivation. For example Ulrich, Keller, Hoenig and Grön (2014) and Ulrich, Keller and Grön (2015) found reduced activity of the medial prefrontal cortex, an important structure in self-referential processing. Conversely, however, research by Yoshida et al. (2014) and Harmat et al. (2015) using functional near infrared spectroscopy (fNIRS) to test prefrontal activation found no reduction in activity, suggesting that a wide-ranging mechanism of hypofrontality may be overly general. Support for hypofrontality comes mainly from studies finding reductions in cognitive function as a result of exercise (see Stoll & Pithan, 2016). Whether this state is representative of a general flow mechanism is questionable.

1.2.1.5.2 Neural synchronisation theory

Weber, Tamborini, Westcott-Baker and Kantor (2009) have suggested that synchronized neural oscillation of attentional networks (and subsequently reward networks) provides a potential explanation of the enhanced attention found during flow. Neurons fire at varying rates at rest, but oscillatory activity in groups of neurons can arise from feedback connections between them, particularly in the alpha and theta bands. Synchronous neural firing is proposed as a solution to the binding problem of consciousness (Crick & Koch, 1990), as groups of neurons that have become synchronized may coordinate their processing. Basing their view of attention on Posner, Inhoff, Friedrich and Cohen's (1987) tripartite theory, Weber et al. suggest that coordinated firing of alerting, orienting and executive attention networks, alongside reward networks, gives rise to the experience of flow, as all attention and reward systems are working in harmony.

Weber suggests synchronous activity provides energetic optimization in the neural system, which fits neatly with Csikszentmihalyi's description of flow as psychic 'negentropy', the state in which attention is organised to flow freely in the present task, in contrast to the disorder of entropy. They suggest that this optimization explains both the rewarding aspect of flow (de Manzano et al., 2013; Klasen, Weber, Kircher, Mathiak & Mathiak, 2011) as well as its effortless nature. Neuroimaging results provide some support for this view, as higher attentional networks have been found to be active during flow (Ulrich, Keller, Hoenig, Waller & Grön, 2014; Ulrich, Keller & Grön, 2016), but as yet there is no support for an improved synchronisation between networks. This view of flow accounts for some of the important features, but as yet does not explain why a challenge-skill balance gives rise to this particular pattern of activation. It also requires a characterization of flow as an 'all or nothing' state (i.e. networks are either synchronized or they are not), which is in contrast to Csikszentmihalyi's description of a continuum of flow experiences.

1.2.1.6 Psychophysiological findings

Flow research in sport has made very little use of direct measurement techniques, but research within other domains has utilised techniques like heart rate, EEG and fMRI. Some of these findings that pertain to the role of attention will be addressed later, but a significant group of studies have utilised direct measurement to build a picture of arousal and affect during flow. Given the way in which flow is described as a state of optimal arousal for performance (Jackson, 1995), psychophysiological findings may be crucial in understanding how flow relates to other performance states like clutch (Swann, Crust & Vella, 2017).

The hypothalamic-pituitary-adrenal axis (HPA), a pathway responsive to stress, produces the glucocorticoid cortisol, which has been linked to flow. Keller et al. (2011) found a moderate increase in cortisol to have a positive relationship with flow, while Peifer, et al. (2014) demonstrated an inverted U relationship between flow and cortisol, again suggesting a moderate level of HPA activation was facilitative (see also Brom et al., 2014 and Peifer, Schächinger, Engeser, & Antoni, 2015). Cortisol is potentially a by-product of flow, but it may also be flow-enhancing during a longer experience, given the evidence that it facilitates learning and memory (Wiegert, Joëls & Krugers, 2006); protects against distracting auditory stimuli (Fehm-Wolfsdorf & Nagel, 1996); enhances self-reported concentration (Born, Hitzler, Pietrowsky, Pauschinger & Fehm, 1988); and raises blood glucose levels (Benedict et al., 2009), which facilitates performance in attention tasks (Gailliot et al., 2007). However it does denote a level of demand and stress that is not traditionally associated with the experience of flow.

Elevated demand during flow has also been shown through heart rate monitoring, for example, Gaggioli, Cipresso, Serino and Riva (2013) found activation of sympathetic nervous system and increased heart rate during everyday flow using experience sampling with wearable HR monitors. Generally an inverted-U relationship between flow and sympathetic arousal, with a positive linear relationship with parasympathetic arousal (Peifer et al., 2014; Peifer et al., 2015), indexed by heart rate variability (HRV) has been found, although results are somewhat variable.

Specifically, the spectral band of 0.04-0.15Hz, termed low-frequency HRV (LF-HRV), has been shown to reflect physiological arousal due to mental stress (del Paso, Langewitz, Robles, & Pérez, 1996; del Paso, González, & Hernández, 2004; Yasumasu, del Paso, Takahara, & Nakashima, 2006). LF-HRV is generally thought to reflect sympathetic influence, although this is disputed by some researchers (see Berntson et al., 1997). In flow research there have been contrasting findings regarding LF-HRV, as Keller et al. (2011) found balancing challenge and skills produced positive subjective reports, but decreased HR variability, indicating mental effort (however flow ratings were not taken). Tozman et al. (2015) also found increasing demand (boredom vs flow vs anxiety) lead to reduced LF-HRV, showing flow to be a case of physiological arousal. However Peifer et al. (2014) found an inverted U relationship between flow and LF-HRV, suggesting that once a moderate level of arousal is reached, additional arousal is detrimental. This may also be reflective of an optimal level of mental workload.

High-frequency HRV (HF-HRV) in the 0.14-0.4 Hz band is a reliable indicator of parasympathetic influence (Porges, 1995), and is also reduced during demanding tasks (Backs, Ryan & Wilson, 1991). HF-HRV is linked to efficient allocation of attention (Thayer, Hansen, Saus-Rose & Johnsen, 2009), and better executive functioning (Hansen, Johnsen & Thayer, 2003), and as such we might expect a positive linear relationship with flow, however the cognitive demands during flow could counteract this effect. Nonetheless, a positive linear relationship of HF-HRV with flow was found by Peifer et al. (2014), which may facilitate these attentional benefits. In addition it indicates parasympathetic influence that is important in controlling arousal from the sympathetic branch of the ANS. De Manzano et al. (2010) suggest that moderate sympathetic and high parasympathetic arousal has been found to be the most beneficial state for flow, or characterising the state most closely.

Research has also linked flow with positive affect (PA) (Hoffman & Novak, 1996; Chen, 2006; Kivikangas, 2006; Rogatko, 2009; de Manzano et al., 2010), which supports Csikszentmihalyi's (1975) description of flow as a positive experiential state. Direct measurement has supported this contention, as facial EMG has been used to investigate flow utilising the zygomaticus major (ZM), the 'smile muscle', and the corrugator supercilli (CS), the 'frown muscle', to test increases in enjoyment based on a two dimensional view of emotion as a combination of valence and arousal (Lang, 1995). Kivikangas (2006) found a negative relationship between flow and the CS while Nacke and Lindley (2008, 2010; also Nacke, Grimshaw & Lindley, 2010) found significant activation of the ZM during flow, both indicating positive emotion. Activity of the ZM has also been identified in flow during piano playing by de Manzano et al. (2010), who found the flow state to be characterised by decreased heart period, increased respiratory depth and positive affect, framing it within Lang's (1995) model of affective space as a state of high arousal and positive valence.

The relationship of PA with creativity, a common feature of flow, is fairly well established (Isen, Daubman & Nowicki, 1987, Estrada, Young, & Isen, 1994), and the role of PA in making flow a rewarding and intrinsically motivated (Isen & Reeve, 2005) activity is clear. The attentional aspects of flow may also owe something to PA, which may enhance working memory (Ashby, Valentin & Turken, 2002), executive attention (Ashby & Isen, 1999) and the ability to screen out distractors (Compton, Wirtz, Pajoumandm Claus & Heller, 2004). It is also linked with improved breadth of attentional selection (Rowe, Hirsh & Anderson, 2007), although in approach motivated positive affect, which we may see in flow, it has been shown to narrow attentional focus (Gable & Harmon-Jones, 2008).

PA has been demonstrated to affect perception of difficulty/pain (Kahneman, 2011; Zautra et al., 2005), which may contribute to the perceived effortlessness of flow (Bruya, 2010), as Kahneman (2011) states that cognitive ease is both a cause and a consequence of pleasant feelings. This also links well to research highlighting the role of dopamine (de Manzano et al., 2013; Klasen et al., 2012; Gyurkovics et al., 2016) and reward pathways (Weber et al., 2009) during flow. Overall, psychophysiological findings suggest flow to be a state of moderate arousal and mental effort, accompanied by positive affect, which may contribute to reduced feelings of effort and some enhanced attentional processes. However, inferring complex mental states from a physical recording must be done with caution (Cacioppo, Tassinary & Berntson, 2007; Cooke, 2013).

1.2.1.7 Interim summary

So far, the early approaches to flow and Csikszentmihalyi's flow theory have been outlined and conceptual issues surrounding the study of flow, and in particular flow in sport, have been discussed. Major issues within the literature relate to the lack of experimental approaches and objective measurement, and the limited understanding of the mechanisms responsible for flow. Within Csikszentmihalyi's (1990) description of flow, key features of the experience point to changes in attention; focused concentration, action-awareness merging and loss of self-consciousness. The theories of flow discussed also highlight the importance of attention in flow, whether it is a reduction in conscious processing (Dietrich, 2003) or an improved synchronisation of attention networks (Weber et al., 2009). Similarly, psychophysiological studies have indicated flow to involve increased mental effort, pointing to the role of attention. Therefore the role of attention in flow may provide some objective measurements of changes during flow, as well as a potential proximal mechanism for both the beneficial effects and the experiential components of flow. Therefore a more detailed outline of attentional systems, attentional selection and their relationship to flow is required.

1.2.2 Attention

1.2.2.1. Attentional selection

The major contention of this thesis is that the core features of flow point to changes in attentional processes, and therefore investigations of attentional processes should provide an effective way of understanding the occurrence of flow and contribute to theory development. In addition, measures of visual attention may help to provide objective measurements of flow that are currently lacking. Knudsen (2007) describes attention as the mechanism of selection for information that gains access to working memory from the vast array available from the world, from internal states and from stored memories. Information is selected based on its signal strength, which is principally determined by the interaction of top-down bias signals and bottom up salience filters. Top-down bias signals direct the individual to goal-relevant stimuli while bottom-up salience filters enhance the influence of stimuli of learned or biological relevance. The process of competitive selection determines which information enters working memory and subsequently directs gaze behavior (see Figure 1.2).

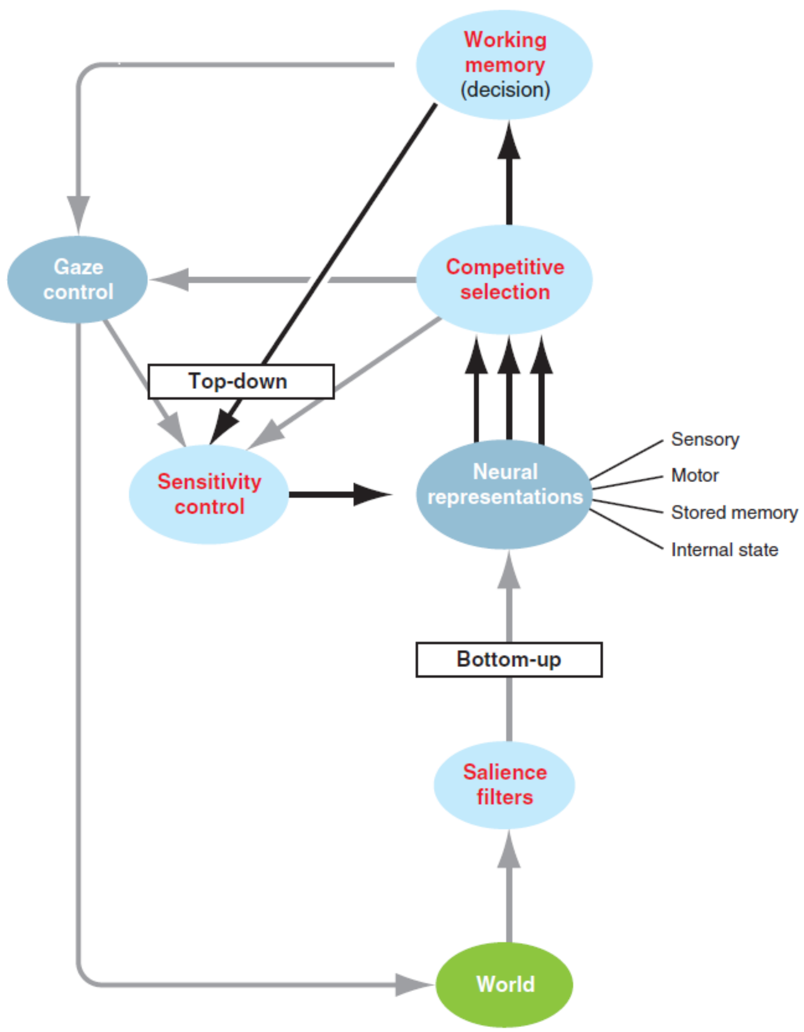

Figure 1.2; The functional components of attention, from Knudsen (2007)

This interaction between the top-down and bottom-up (or goal-directed and stimulus-directed) influences on attentional selection determine the extent to which incoming information will be processed. These two influences are spatially distinct in the brain, as described by Corbetta and Shulman's (2002) model of visual attention. Cognitive factors such as knowledge, expectations and goals guide top-down attention through a stream of processing which includes intraparietal cortex and superior frontal cortex. Saliency factors influence attention through the stimulus driven, bottom-up system with a stream including temporoparietal and inferior frontal cortex. Within Corbetta and Shulman's model they are referred to as dorsal and ventral streams respectively.

Although described as independent networks, they have an interactive effect on attentional selection as salience can be influenced by task relevance. In the context of sport, top-down influences may relate to watching the ball, focusing on the target or observing the strategies of other competitors. The bottom-up system however can act as a circuit breaker and interrupt this focus of attention, due to the saliency of distracting information such as pain, threatening opponents or unexpected noises.

With regards to the visual domain, neuroimaging has identified three networks that underlie the functions of visual attention: alerting, orienting and executive control (Posner & Petersen, 1990; Carrasco, 2011). Alerting maintains a state of sensitivity to incoming stimuli, orienting selects information from sensory input and executive networks resolve conflict between possible responses. Visual attention can also be categorized into three main types: spatial attention, where attention is deployed to a location either overtly or covertly (without movement of the eyes); feature based attention which is directed to specific aspects of objects, regardless of their spatial location; and object based attention which is guided by object structure (Carrasco, 2011). These differences in selection for visual stimuli are important for the information that is acquired in a task, and are achieved through the orienting mechanism.

1.2.2.2 Attention control in sport

Attention control refers to the balance between goal-driven and stimulus-driven influences, with good attention control a result of predominantly top-down influences (Egeth & Yantis, 1998). Research in sport strongly illustrates the importance of optimal attentional control for expertise, with skilled performance related to effective orientation of visual attention (Vickers, 2007) rather than trait differences in attentional capacity (Memmert, Simons & Grimme, 2009). A meta-analysis by Mann, Williams, Ward and Janelle (2007) identified that the visual attention of experts differed from novices in a number of ways, for example speed in picking up perceptual cues, quiet eye period and efficiency of visual search behaviour. For example, Savelsbergh, Williams, Van Der Kamp and Ward (2002) showed visual search to be more efficient in expert goalkeepers, with more attention directed to information crucial for anticipatory movements.

Attentional allocation has also been shown to underlie improved performance in various sporting tasks (Abernethy, 1988, 1990; Williams & Davids, 1998). The attentional mechanisms that bias the processing of incoming information are therefore responsible for attention control and exert a substantial influence on performance. Illustrative of the important role of attention is research demonstrating that disruptive effects of anxiety on performance are mediated by impaired attentional control (Janelle, 2002; Eysenck, Derakshan, Santos & Calvo, 2007; Wilson Wood & Vine, 2009). Two tasks used in this thesis, the basketball free throw and racing driving, have particular visual behaviours indicative of attention control. These will now be outlined.

1.2.2.3 Visual attention control in aiming tasks – the quiet eye

One instance of optimal visual attention control in sport is the quiet eye (QE, Vickers, 1996). The quiet eye is a fixation or tracking gaze that precedes a movement in an aiming task and provides time when neural networks can be organised to control the upcoming movement (Vickers, 2009; Williams, Singer & Frehlich, 2002). In a motor task, the quiet eye is defined as the final fixation to a specific location or object in the visuo-motor workspace, within 3° of visual angle[2] for a minimum of 100ms (Vickers, 1996; 2007). The onset occurs prior to the final movement in the task and the offset occurs when gaze leaves the object or location by more than 3° for a minimum of 100ms. It is thought to reflect the influence of the dorsal stream of visual attention (Vine & Wilson, 2011) and hence goal-directed control.

Longer quiet eye durations have been found in expert performers (Williams, Singer & Frehlich, 2002; Mann et al., 2007) and in successful versus unsuccessful trials (Vickers, Rodrigues & Edworthy, 2000; Reinhoff et al., 2015). Training in QE also improves performance (Harle & Vickers, 2001; Vine, Moore & Wilson, 2011), guards against the effects of anxiety (Vine & Wilson, 2011) and

[2] Sometimes defined as 1°, e.g. Vine, Moore and Wilson (2011).

aids skill acquisition (Moore, Vine Cooke, Ring & Wilson, 2012; Vine, Moore & Wilson, 2014). The quiet eye is thought to reflect both pre-programming and online control in targeting and interceptive tasks (Sun, Zhang, Vine & Wilson, 2016; Walters-Symons, Wilson & Vine, 2017).

Basketball (and netball) shooting is referred to as a far aiming task because once the ball leaves the hand, control is lost, unlike near aiming tasks where online control can be exerted until the target is reached. Vickers' (1996) initial studies into the quiet eye demonstrated that in the free throw, expert gaze is characterised by a longer, earlier fixation to the target (the hoop or backboard) prior to the initiation of the shot phase. Based on the behaviour of experts, Vickers (1996) suggested that key information was obtained in the preparation phase, as experts would blink or avert their gaze as the ball was lifted and occluded the target, suggesting key programming had already occurred. Therefore visual expertise in the free-throw may involve a longer fixation with earlier onset on the basket. This allows pre-programming of movements, leading to performance benefits. This is supported by the efficacy of QE training in expediting skill acquisition in the basketball free throw (Vine & Wilson, 2011; Harle & Vickers, 2001). Overall, the quiet eye may be both an indicator of when attention control is good, and a way of training good attention in aiming tasks (see Lebeau et al., 2016 for a recent meta–analysis and review).

1.2.2.4 Visual attention control in driving

Driving simulators have been widely used to study the effects of mental workload, fatigue and divided attention on driving performance (Thiffault & Bergeron, 2003; Brookhuis, Van Winsum, Heijer & Duynstee, 1999; Alm & Nilsson, 1994), for applications to road safety. Research has highlighted the importance of visual attention in effective driving performance, for example, Readinger, Chatziastros, Cunningham, Bülthoff and Cutting, (2002) demonstrated that deviation from straight line driving was proportional to the deviation of gaze from a central location.

Generally, effective visual attention control in driving reflects the way that information can be most effectively obtained, with longer, less numerous fixations being more efficient due to saccadic suppression (Bridgeman, Hendry, & Start, 1975; Mann et al., 2007). As demands increase during driving, attention has been found to narrow (Wilson, Chattington & Marple-Horvat, 2008), which may reflect a better deployment of resources to deal with the challenge, as predicted by Easterbrook's cue-utilization hypothesis (1959). For example Chapman and Underwood (1998) found dangerous situations were characterised by a narrowing of visual search, shown by an increase in fixation durations, a decrease in saccade angular distances, and a reduction in the variance of fixation locations. Conversely, in simulated racing tasks Murray and Janelle (2003) and Wilson, Smith, Chattington, Ford and Marple-Horvat (2006) linked increased fixations to inefficient visual attention and hampered driving performance. Longer, task focused fixations may reflect goal-directed influences on attention, while more numerous, more scattered fixations suggest increased influence of the stimulus driven system (Eysenck et al., 2007).

A particular visual behaviour, tangent point steering, is thought to reflect optimal attention control whilst driving (Chattington, Wilson, Ashford & Marple-Horvat, 2007). When negotiating a bend in the road, Land and Lee (1994) found that drivers look to the outer part of a corner, the 'tangent point', to guide steering. As well as providing information regarding the upcoming road, this movement of the eyes is thought to assist neural centres controlling steering (Wilson, Chattington & Marple-Horvat, 2008). Eye movements are sufficiently important for steering that moving gaze into the upcoming corner provides steering benefits even when it provides no visual information (Wilson, Stevenson, Chattington & Marple-Horvat, 2007). The coordination between eye movement and steering has also been found to be an effective predictor of driving performance (Wilson, Chattington & Marple-Horvat, 2008; Wilson et al., 2007) and driver distraction (Yekhshatyan & Lee, 2013). One explanation of this coordination suggests that eye movements feed into the oculomotor controller, as neural centres controlling eye movements direct neural centres controlling steering (Marple-Horvat et al., 2005; Wilson, Chattington & Marple-Horvat, 2008). Much as the QE reflects goal-directed control in a basketball task, focusing on the tangent point may similarly reflect goal-directed vision during driving.

1.2.2.5 Attention during flow

Dormashev suggests that "prolonged effortless concentration of attention is the principal characteristic of the flow experience" (2010, p.306) and attention is clearly a prominent factor during flow, based on the dimensions outlined by Csikszentmihalyi and reports of flow experience. In flow, athletes report an all-consuming focus, where pain, distracting thoughts and other aspects of the environment do not enter their awareness (Jackson & Csikszentmihalyi, 1999). This indicates that attentional mechanisms are strongly selecting task-relevant over task-irrelevant information.

In general Csikszentmihalyi subscribes to Daniel Kahneman's (1973) view of attention as a finite resource of psychic energy that selects information to appear in consciousness. He suggests that entering flow is a function of how attention is focused in the present by the activity's structural conditions. The intense concentration described during flow is another way of inferring a full investment of attention.

Csikszentmihalyi and Nakamura (2010, p.187) suggest that "attention is most focused when environmental challenges are in balance with the person's skills", as each additional investment of attention has immediate effects. Flow theory proposes that flow depends on a balance of challenges and skills, and similarly optimal attentional engagement arises from a balance in the information to be processed, and the information processing capabilities of the system. Informational overload leads to divided attention and impaired performance (Kahneman & Treisman, 1984), while a lack of information leads to insufficient arousal to maintain good attentional control (Kahneman, 1973; Eastwood, Frischen, Fenske, & Smilek, 2012). Therefore the challenge-skill balance is required to appropriately engage attention during flow.

Csikszentmihalyi (1990) identifies within the experiential dimensions of flow; a sense of control, a merging of action and awareness, distortion of time, loss of self-consciousness and intense concentration. These elements all point to a state of focused attention which is widely alluded to in the flow literature, but specific mechanisms are yet to be outlined. For example, de Manzano et al.

(2010) make reference to the importance of attentional processes; "we forward the hypothesis that flow is experienced during task performance as a result of an interaction between emotional and attentional systems" (p.309) but are not explicit about specific mechanisms. To allow researchers to advance flow theory and for practitioners to better manipulate flow, hypotheses about specific attentional processes may be needed.

1.2.2.5.1 Attention control

Flow is described as being task focused and immune from distraction (Jackson & Csikszentmihalyi, 1999), suggesting that attention control is particularly good, due to limited disruption of goal-directed control. Applying this to Knudsen's (2007) characterisation of attention, we could describe the top-down sensitivity control mechanism as guiding competitive selection and hence the information that enters working memory, either due to greater sensitivity control or reduced influence of salience factors. In the earliest psychophysiology study relating to flow, Hamilton et al. (1984) found that in people identified as highly intrinsically motivated (or autotelic), increases in attention led to decreased effort. In interpreting these findings, Csikszentmihalyi (1990) suggested that individuals with an autotelic personality were able to shut down mental activity related to irrelevant processes while maintaining high attention in channels related to the task. This may be an early suggestion that during flow, the balance of task-relevant and task-irrelevant information processing is particularly good. Similarly Goleman (1995) suggested that flow is connected to a decrease in cortical activation where a minimum of energy leads to maximum efficiency. This is reminiscent of neural efficiency explanations of expertise in sport (Hatfield & Kerick, 2007). However, measurement of attention during flow is required to verify if this is indeed the case.

This view of attention during flow is supported by gaming research on immersion, a state similar to flow. Immersion indicates total absorption, but can be more passive than flow, for example when watching television. Jenette et al. (2008) found participants' number of fixations to decrease as they became more immersed in a first person shooter game. Conversely, in a non-immersive condition there were significantly more fixations, increasing over time as visual attention became less goal-focused. Similarly Cheng (2014) using an educational computer game also found that during immersion, students exhibited a significantly lower number of fixations, indicating a reduced search rate. Anxiety research has suggested increased search rate with longer fixations to reflect influence of bottom-up factors on visual attention (Janelle, 2002; Allsop & Gray, 2014; Vine et al., 2014). This inverse pattern during immersion suggests limited influence of stimulus salience and that orienting of attention was determined by top-down factors.

While this evidence points to a strong goal-directed influence during flow, the state of immersion may not be fully representative of flow, particularly as it is independent of the crucial C-S balance (Brown & Cairns, 2004). Therefore further research is needed to establish whether objectively measurable changes exist during flow. Recent neuroimaging research has indeed provided evidence that neural networks associated with top-down influences are highly active during flow. For instance Ulrich et al. (2016) identified activation of brain areas associated with the Multiple Demand (MD) network during flow in an arithmetic task. The MD system (Duncan, 2010) reflects activity of a functionally general network of brain regions associated with a variety of cognitive challenges. The MD network involves areas of the prefrontal and parietal cortex, including: the inferior frontal sulcus, anterior insula, pre-supplementary motor area and in and around the intraparietal sulcus. Duncan (2010; 2013) links the MD system to goal-directed behaviour, fluid intelligence and selective visual attention. In particular it plays a function in organizing multi-step behaviour. Interestingly, Ulrich et al. found brain areas related to the MD network to be activated *more* during a flow level of difficulty than a harder level of difficulty, with activation associated with performance.

Alternatively the areas identified by Ulrich et al. (2016) could also be interpreted as reflecting increased activity of the dorsal stream of attention (Corbetta & Shulman, 2002). The MD system depends on areas of parietal and frontal cortex which are identified by Corbetta and Shulman (2002) as part of the fronto-parietal dorsal stream. Indeed Duncan (2013) notes the overlap between MD and dorsal networks, and therefore the findings of Ulrich et al. may also be instructive of the important role played by the dorsal stream in promoting goal-directed control of attention during flow. Either way, these findings are indicative of top-down control of attention, as the MD system serves to coordinate a series of multi-step behaviours, guide selective focus to task-relevant information and provide cognitive control. These findings strongly challenge views of flow as a state of automaticity, with reduced frontal influence (Dietrich, 2004), and highlight that during flow supervisory attentional and cognitive control systems of the brain are highly active.

Attentional processes during flow may also be affected by neurotransmitter activity, as findings highlight a role for dopamine. Dopamine pathways are primarily associated with reward networks in the brain (Schultz, 2006), but also modulate attentional focusing (Nieoullon, 2002), error monitoring (Holroyd & Coles, 2002; Ridderinkhof, van den Wildenberg, Segalowitz & Carter, 2004) and response inhibition (Congdon, Lesch & Canli, 2008; Chambers, Garavan & Bellgrove, 2009). De Manzano et al. (2013) have demonstrated that flow prone individuals have increased availability of dopamine D2 receptors in the striatum, which is functionally related to selective attention (Nieoullon, 2002). Gyurkovics et al. (2016) have identified flow proneness to be related to a D2 receptor coding gene, and suggest that the relationship between dopamine and flow may be through reduced impulsivity and more effective response inhibition.

Reduced dopamine action is associated with impulsive behaviour (Dalley & Roiser, 2012) evidenced by its therapeutic effects on impulsivity in ADHD (Kollins & March, 2007), so individuals with enhanced D2 availability are predisposed to the behavioural control and monitoring benefits of dopamine. The findings related to dopamine fit with our wider discussion of attentional control, which requires response inhibition and impulse control (Miyake, Friedman & Emerson, 2000), both of which are modulated by dopamine action (Dalley & Roiser, 2012; Nieoullon, 2002). These findings also have important implications for individual differences in flow and the 'autotelic personality' (Csikszentmihalyi, 2000), which may now have a biological basis.

Overall these findings point strongly to an important role for higher order attention control mechanisms during flow, although this is perhaps not the dominant approach within the literature (Dietrich, 2006; Jackson, 1996; Swann et al., 2016). The importance of optimal control of attention is highlighted by its negative corollary; as disrupted attentional control under pressure has been shown to impair motor performance (see Eysenck & Wilson, 2016 for review). For example, there is ample evidence that conditions designed to increase anxiety and reduce flow can impair visual attention (indexed via quiet eye) and subsequent performance in a range of sport skills; including basketball free-throw shooting (Wilson et al., 2009), soccer penalties (Wood & Wilson, 2010) golf putting (Vine et al., 2013); and biathlon (Vickers & Williams, 2007). The use of technology, such as mobile eye trackers, to measure objective, task-relevant indices of visual attentional control (e.g., quiet eye) may therefore provide useful insights into the flow process while it unfolds. A remaining issue however, relates to the ease of performance associated with flow. The top-down systems discussed are more usually associated with felt effort (Sarter, Gehring & Kozak, 2006), but those in flow report the experience as effortless (Ullén, de Manzano, Theorell & Harmat, 2010; Swann et al., 2016). However there are reasons to believe that this apparent disparity can be reconciled.

1.2.2.5.2 Mental effort

Traditional models of attention suggest that as a task becomes more difficult (requiring cognitive or executive control), more mental energy (or effort) is required (Kahneman, 1973). In addition, mental effort has a physical basis, leading to changes in both central (neural) and peripheral (e.g. cardiovascular) psychophysiological indicators (Berntson et al., 1997; Berka et al., 2007). However flow presents a challenge for attention researchers, as difficult tasks are met with a seeming *decrease* in felt effort (Bruya, 2010; Nakamura & Csikszentmihalyi, 2010). This disparity presents a major tension in flow research.

During flow, individuals report that a task that may have begun as effortful has become effortless, as they became fully absorbed. Therefore either the task has become easy, and does not require mental effort, or the subjective experience has become dissociated from the objective level of mental work. Several studies utilising objective markers of mental effort during flow, would suggest the latter. For example, Gaggioli, Cipresso, Serino and Riva (2013) revealed that everyday flow experiences were indexed by increased sympathetic activity (increased heart rate), suggesting that the perception of ease is not reliably reflected in physiological activity.

As discussed previously heart rate variability (HRV), the fluctuations in beat-to-beat interval, provides a more sensitive measure of mental effort (Berntson et al. 1997; Jorna 1992) and attention (Backs, 1997; Backs & Ryan 1992). In flow research, Keller et al. (2011) found that a balance between challenge and skills (a precursor to flow) produced positive subjective reports, but decreased HRV, indicating increased mental effort. Likewise, de Manzano, et al. (2010) found decreased HRV was related to instances of increased flow experience during piano playing, and Tozman et al. (2015) found that a flow-task reduced HRV in the low frequency component (i.e. required more mental effort) compared to an objectively easy task. Finally, Peifer et al. (2014) found an inverted-U relationship between flow and low frequency HRV; suggesting that once a moderate level of mental effort is reached, additional mental load is detrimental. However a note of caution is warranted regarding the interpretation of HRV as an index of mental effort. Jorna (1992) identifies that mental load can be hard to differentiate from stress, while variability can also be influenced by factors such as respiration, muscle activity, body position and physical fitness. Therefore Jorna suggests that mental effort should only be inferred with additional evidence that cognitive demands have increased.

However, given the manipulation of task difficulty in these studies it is reasonable to conclude that during flow we see an elevated level of mental effort, but perhaps within a moderate range (Peifer et al., 2014). One potential reason why this effort is not felt is the positive affect elicited during flow (Nacke & Lindley, 2008; 2009). Positive emotion has been shown to buffer against the perception of difficulty (Kahneman, 2011, Zautra, Johnson & Davis, 2005) and may mask the feelings of effort. An alternative perspective can be found in the work of Matthew Botvinick on the conflict-monitoring hypothesis (Botvinick, Braver, Barch, Carter & Cohen, 2001), which indicates how flow may make a task feel easier. Subjective mental effort arises from a change in cognitive control, when the demands of the situation are appraised as not being met. During flow challenges and skills balance, performance is fluent and no change in cognitive control is necessary (McGuire & Botvinick, 2010). As highlighted by Dobrynin (1966), effortless attention occurs when the task is fully absorbing, and hence cognitive control is not needed to maintain focus.

The anterior cingulate cortex is proposed as a key structure within cognitive control and conflict monitoring (Botvinick et al., 1999; Botvinick, Cohen & Carter, 2004; Van Veen & Carter, 2002), serving to monitor performance and assess whether attention needs to be refocused or redirected. The importance of the ACC in the perception of effort is demonstrated by Naccache et al. (2005), who found that a patient with an ACC lesion did not experience effort in a Stroop task, despite exhibiting normal executive control. In addition, Posner and colleagues (2010) suggest that early stages of meditation may depend on ACC to exert control, with activity receding as it becomes more effortless. Neuroimaging studies provide evidence that the same may be occurring during flow. During flow in a video game, Klasen et al. (2011) found reductions in rostral ACC activity associated with increased focus, and reductions in dorsal ACC activity associated with clear goals in the task. Ulrich, Keller and Grön (2016) also found reduced neural activation in the right anterior cingulate during a flow level of arithmetic task. These findings indicate how the nature of a flow task, providing clear goals and holding an individual's focus, may allow reductions in the need for cognitive control through reduced activity of the ACC, and subsequent reductions in felt effort.

Therefore current research presents possibilities to understand the paradoxical nature of effort during flow through established attentional mechanisms. An additional factor indicative of attention during flow, the degree of automaticity, may further help to explain how task demands are not felt.

1.2.2.5.3 Automaticity

Information is processed by two general brain systems. The explicit system is rule based, context general, its contents can be expressed verbally and is therefore available to conscious awareness (Moors, 2016). The implicit system acts through task performance and is not verbalisable or available to conscious awareness (Schacter, Chiu & Ochsner, 1993). It develops through experiential learning and is faster partly because it does not form higher order representations. The systems are distinguishable through function and brain anatomy (Squire, 1992).

The implicit system is responsible for automated control, which is generally, though not always, thought to provide benefits for action in terms of efficiency, fluency and reduced resource allocation (Bargh, 1994; Toner, Montero & Moran, 2015). Automaticity develops through practice and is a feature of sporting expertise (Fitts & Posner, 1967). Automated performance has been suggested to underlie the flow state by Dietrich (2004) and other researchers (Jackson, 1992; 1995; Pates, Cummings & Maynard, 2002; Swann et al., 2016). Dietrich's hypofrontality theory (see 1.2.1.5.1) suggests that automaticity is achieved by a reduction in prefrontal activation, and the use of the implicit system leads to both smooth performance and an absence of effort.

Despite the appeal of this type of explanation, evidence for the claim is limited, although initial electroencephalogram (EEG) research does provide some support. EEG assesses cortical activity through electrodes placed on the scalp, which give information regarding rhythmic neural oscillations, measured in Hertz (Hz). Wolf et al. (2015) demonstrated that flow during table tennis imagery was related to a reduced influence of verbal-analytic processing on motor control, which was subsequently related to expertise. EEG recordings showed relative deactivation (higher alpha power) of a left temporal site (T3), associated with verbal-analytic processing, compared to the corresponding right site (T4) which reflects visuospatial processing. Their results suggest that the flow experience may involve a shift away from verbal-analytic influence to a more automatic mode of operating; the same shift that has been found with a progression from novice to expert performance (Deeny, Hillman, Janelle &

Hatfield, 2003), and from more explicit to more implicit forms of motor performance (Zhu, Poolton, Wilson, Maxwell & Masters, 2011).

Automaticity can be loosely described as the absence of attention (Moors, 2016), but following HRV findings indicating mental effort, it seems likely that there are appreciable attentional demands during flow, and hence complete automaticity is unlikely. Csikszentmihalyi and Nakamura (2010) suggest that the importance of automaticity during flow lies in allowing automated sequences to take care of themselves, so that *more* attention can be paid to essential aspects of the activity. They suggest that effortless attention is rarely fully automatic, and a person is often more open, alert and flexible within the structure of the activity. If flow enables an enhanced degree of implicitness in motor control we can expect to see performance benefits (Singer, 2001; Williams & Ford, 2008), but demands on executive processes during complex sporting tasks may mean effortful attention is also required.

1.2.2.5.4 Self-awareness

An additional factor that characterises attention during flow is a reduction in self-referential processing. Self-awareness has often been linked with negative performance consequences in sport (Masters, 1992; Beilock & Carr, 2001), although a complete absence of self-monitoring is not necessarily facilitative of expertise (Toner, Montero & Moran, 2015). Awareness of the self is thought to recede during flow as attention becomes more external and task focused which may account for aspects of flow's phenomenology as well as potential performance benefits in sport.

Csikszentmihalyi (1975; 1990) suggests that when fully absorbed in a flow inducing activity, attention is directed towards the goal and the self recedes. In what at first seems like a contradiction, Jackson and Csikszentmihalyi (1999) describe how the athlete may have enhanced awareness of their body during flow. However, this is distinct from self-awareness because the body begins to dissociate from the self. Bodily actions are reported to feel as though they are moving on their own, without conscious willing. This reduction in self-consciousness during flow is supported strongly by recent neuroimaging findings.

Ulrich et al. (2014) investigated flow during differing levels of arithmetic challenge, using Magnetic Resonance Perfusion Imaging. Reduced relative cerebral blood flow (rCBF) was found in the medial prefrontal cortex, an area strongly linked to self-referential processing (Northoff et al., 2006; Jenkins & Mitchell, 2011; Farb et al., 2007) and an important part of the brains Default Mode Network (DMN, Raichle et al., 2001; Andrews-Hanna, 2012; Buckner, Andrews-Hanna & Schacter, 2008). The DMN is an interacting system of brain regions including the posterior cingulate cortex, medial prefrontal cortex and angular gyrus, which are active during passive states. Activity in the DMN is associated with mind-wandering and thinking about the self, past and future, and is known to be reduced during goal-directed behaviours (Raichle et al., 2001). As well as medial PFC, Ulrich et al. found reduced activity in other regions associated with the DMN (e.g. angular gyrus, supramarginal gyrus, parahippocampal cortex). While reduction of this network is not unique to flow, it highlights the importance of reduced self-awareness and internal focus during the state.

Further research by Ulrich et al. (2016) using fMRI similarly found reductions in medial prefrontal areas and brain regions associated with the DMN. Goldberg, Harel and Malach, (2006) found reduced activity in self-related structures during sensory processing, likening it to 'losing yourself in the act', which is strongly suggestive of Csikszentmihalyi's (1990) dimension of action awareness merging. Ulrich et al. suggest that this reduced self-awareness may also contribute to another facet of flow; the positive nature of the experience. As self-referential processing is associated with negative affectivity (Brewer at al, 2011; Lemogne et al., 2011), reductions in activity of the medial PFC and DMN may contribute to a positive experience. Further, an fMRI study by Garrison et al. (2013) applying real time neurofeedback in experienced meditators found reductions in areas of the DMN to link to effortless doing and contentment.

Reduced awareness of the self may contribute, not just to the experience of flow, but to its benefits for performance. In sport, awareness of, and focus on, the self is associated with impaired skill learning and performance (Baumeister, 1984; Beilock & Carr, 2001; Lewis & Linder, 1997; Masters, 1992). Wulf and Lewthwaite (2010) outline the self-invoking trigger hypothesis to describe how activation of the self-schema by environmental triggers (e.g. instructions, presence of other) can account for a variety of findings on motor learning and performance effects. Wulf and Lewthwaite (2010) link this self-schema system to the functional network of cortical mid-line structures found to be inactive during flow. As such, during flow the athlete may be resistant to the self-inducing triggers and their negative consequences. The reduced activity of the DMN also points to a reduction in internal focus, in favour of focusing externally, on the goal (Nideffer, 1976). Wulf (2013) reports how external focus has been shown to enhance effective and efficient movement, something that is often described in flow, but is yet to be measured empirically.

1.2.3 Summary

In summary, flow research within sport has provided a picture of the state and its antecedents but questions remain regarding the underlying mechanisms, and in particular the specific role of attention. Whilst attention is routinely discussed as a key factor, overt measures to confirm this are yet to be taken in sporting tasks. Imaging studies have begun to identify specific mechanisms but the nature of the tasks used in these restricted paradigms has limited ecological validity. As such research to date has failed to identify causal mechanisms, primarily due to the absence of experimental approaches within sport. Therefore experimental approaches and direct measurement techniques (i.e. psychophysiology) used with other disciplines, such as gaming, may provide a greater understanding of the attentional mechanisms at play during flow.

1.3 Aims of the thesis

This review of the literature highlights two major issues arising from flow research. Firstly, methodological issues exist, relating to the over reliance on self-report and the limited use of direct measurement techniques within the sporting domain. Secondly, there is a need to more closely address the proximal causal mechanisms responsible for flow, in order to develop testable theories and evidence based interventions. As discussed, there is growing evidence for the role of attention, but this has yet to be tested through analysis of visual behaviour. These two issues overlap, as experimental approaches are needed to address both. Therefore, this series of studies has two overarching aims. Firstly to develop experimental approaches to flow in sport, which has relied heavily on retrospective reporting of flow experiences. This type of approach also enables objective measurements to be taken to understand the underlying mechanisms of flow. Therefore, the second aim is to utilise direct measurement of visual attention during flow, to test whether objective changes exist, and whether changes in attention are the driving mechanism behind the flow state. This may contribute to flow theory as well as provide a rationale for future interventions. Four studies were undertaken that developed experimental approaches to flow in sport and used measures of visual attention as an objective indicator of cognitive changes during flow.

Chapter 2 examines firstly whether trait flow is related to individual differences in attention control ability. Secondly it is tested whether this relationship can be measured in a sporting task, utilising a simple manipulation of perceived challenge-skill balance. Quiet eye is used as a measure of sport specific visual attention control.

Chapter 3 develops the experimental method used in study 1, using a more skilled population and generalises across two far aiming tasks, basketball and netball shooting. The quiet eye is again used as a measure of optimal visual attention control to investigate whether self-reported flow experience is linked to objective changes in visual attention.

Chapter 4 again addresses changes in visual attention during flow, but in a simulated driving task to provide a highly immersive environment. As in studies 1 and 2, the manipulation is based on controlling the balance of challenges and skills. Additionally measures of objective and subjective mental effort are used to investigate how a challenging task can be experienced as effortless.

Chapter 5 addresses the causal influence of attention on flow by examining the effects of attentional focus on flow experience, perceptual-motor coordination and performance. In order to establish attention as a causal mechanism, manipulations of attention are required. In addition this addresses whether methods for controlling and training optimal attention are likely to be beneficial applications for enhancing flow.

1.4 Methodology

1.4.1 Measurement of flow

The early measurement of flow focused on interviews, which provided descriptive power in understanding the nature of the state (Csikszentmihalyi, 1975). Interviews allow the researcher to gather a greater depth of information about the experience, but rely on introspection about past events. They also assume accurate introspection about a time when people where highly absorbed in their activity. Subsequently Csikszentmihalyi (1977) used the experience sampling method (ESM) to measure moment-to-moment task engagement and enjoyment. Within the ESM method, participants are alerted by pagers at random intervals during the day, and complete a self-report of the activity they were engaged in and their internal state at the moment of the alarm. The advantage of this approach is that it allows measurement of flow during everyday activities, providing high ecological validity. The measurement is also close in time to the activity, reducing the potential for memory decay. However, prompting individuals to record their flow experience may, ironically, disrupt flow. Within sport research, questionnaire instruments are a common method (Jackson & Eklund, 2002), particularly when the goal is to measure occurrence rather than assess phenomenology. The use of flow scales is central to this thesis, as the general approach was to identify when flow has occurred, and investigate the accompanying psychophysiological changes. Two scales are used in this thesis, which reflect slightly different approaches to flow, and will be described in more detail.

The Flow State Scale and Dispositional Flow Scale

The Flow State Scale (Jackson & Marsh, 1996) and subsequently the Flow State Scale-2 (Jackson & Eklund, 2002) have provided the predominant scale used in sport research. These scales follow closely Csikszentmihalyi's conceptualisation of flow, using 36 items that load onto the 9 dimensions; challenge-skill balance, feedback, clear goals, concentration, sense of control, action-awareness merging, transformation of time, loss of self-consciousness, and autotelicity. These 9 dimensions also load onto a global flow factor. As such, measurement with this scale reflects elements such as absorption, automated movement and the positive experience. The Flow State Scales (Jackson & Marsh, 1996; Jackson & Eklund, 2002) were developed for assessing flow in sport and physical activity, and have been used widely in this area and have been supported by validation studies (Vlachopoulos, Karageorghis & Terry, 2000; Kawabata, Mallett & Jackson, 2008). Additionally a dispositional version, the Dispositional Flow Scale (Jackson & Eklund, 2002), measures trait flow, the disposition to find flow more frequently. This is linked to the idea of an autotelic personality. Again, the 36 items load onto the nine dimensions of flow described by Csikszentmihalyi, plus a global flow factor. The DFS and FSS-2 were selected for studies 1a and 1b, to align the studies with the most common measurement approach used in sport. As the FSS and DFS are 36 item scales they presents difficulties with repeated administration that can lead to questionnaire fatigue. As a result, alternative shorter measures have also been developed, for example Martin and Jackson (2008) have developed 'short' and 'core' flow measures based on the longer FSS-2.

The Flow Short Scale

An alternative short measure is the Flow Short Scale (Rheinberg, Vollmeyer & Engeser, 2003), which is widely used in gaming research (Engeser & Rheinberg, 2008; Tozman et al., 2015). The FSS uses ten questions on a seven point Likert scale such as '*I am totally absorbed in what I am doing*' and '*The right thoughts/movements occur of their own accord*'. This scale reflects a different emphasis on the core elements of the flow experience, as it loads onto the subscales of 'fluency' and 'absorption', as opposed to the 9 dimensions described by Csikszentmihalyi (1990). Fluency and absorption are proposed to reflect the smooth performance and attentional immersion aspects of flow. Key elements such as challenge-skill balance, concentration and smooth movements are retained, but the scale does not include the positive experiential aspect of flow reflected in the scales of Jackson and colleagues. This reflects the view of these researchers that, while flow is a positive experience, this arises because of the absorption in the activity (Engeser & Rheinberg, 2008). As a result, they view absorption as a key element, but the positive nature of the experience as secondary. Therefore, this scale reflects a slightly different perspective on the core aspects of the flow experience. This scale was used in later studies as it allowed repeated administration, and included the key aspects of absorption in the task, and proficient task execution. Additionally, as the scale has been used widely in gaming, it was consistent with a change in experimental method that was more similar to gaming studies. The validity of the scale across a variety of tasks was supported by Engeser and Rheinberg (2008), but while the FSS has been widely used in gaming (e.g. Tozman et al., 2015) it has accumulated limited use within sporting or exercise tasks (although cf. Schüler & Brunner, 2009).

An issue that is not addressed in the flow literature is that of common methods variance. Podsakoff, MacKenzie, Lee and Podsakoff (2003) discuss the variety of ways in which the use of two similar measurements encourages inflation of shared variance, with self-report measures particularly susceptible. For example, individuals prone to agreement with questionnaire items are likely to show a relationship between two self-report measures, even when there is no theoretical basis for a relationship. Given that much of the flow literature in sport involves the use of two self-report constructs (e.g. flow and mental toughness; Crust & Swann, 2013, flow and confidence; Swann et al., 2014, flow and psychological skills; Jackson et al., 2001) the absence of discussion about this issue is a concern.

For flow research to develop, objective, online measurements may be essential. Whilst self-report instruments must be completed retrospectively, direct measures like eye tracking and heart rate recording can be done during the flow experience, without breaking the state of absorption. De Manzano et al. (2010) support the use of objective measures in diagnosing the occurrence of a flow state, suggesting a combination of arousal, positive affect (from facial EMG) and deep breathing may be sufficient to identify flow. Nakamura and Csikszentmihalyi (2002) and Moller, Meier and Wall (2010) support the use of physiological measurement to advance flow research, however current understanding would need to develop significantly to do this, and some researchers would suggest that as flow is a phenomenological state, it can only be measured through introspection. For this reason, direct measures may be best used alongside traditional self-report measures.

1.4.2 Measurement of visual attention

The focus of spatial attention has been described as a spotlight (Posner, 1980), a zoom lens (Eriksen & Yeh, 1985), or a Gaussian gradient (Downing & Pinker, 1985), where visual stimuli within the circumscribed region of space enjoy enhanced processing. The region of the visuomotor workspace that is fixated on is determined by the interaction between top-down and bottom-up influences described by Knudsen (2007) and Corbetta and Shulman (2002). As such point of gaze reflects the state of these underlying cognitive systems. In addition the importance of gaze in the performance of many tasks (Land & Hayhoe, 2001) means that gaze is also a mechanism to explain performance improvements/decrements.

Eye movements occur in order to process information, and serve three main functions; tracking of moving objects, preventing perceptual fading and redirecting foveal vision. The fovea (the central 2^{o} of vision) provides the greatest acuity for visual processing, and as such will, in most cases, be directed to the stimuli in the visual field that are most salient (Rayner, 1998). Whilst the eyes are moving (saccades) information processing is suppressed (Matin, 1974), and must come to a stand still to process information (fixations). The minimum fixation duration for meaningful information processing to occur is generally identified as around 100ms (Duchowski, 2017), with fixations to relevant stimuli key to performance in a variety of sporting tasks (Mann et al., 2007).

The visual modality plays the major role in attention (Knudsen, 2007; Corbetta & Shulman, 2002) with spatial orienting and saccadic control employing overlapping neural systems (Corbetta et al., 1998) and shifts in gaze generally preceded by a shift in attention (Henderson, 2003). Hence assessment of eye movements gives a good indicator of the stimuli being selected for processing at the present moment. However, there are some concerns with using gaze to infer allocation of attention, as eye movements and attention are dissociable (Hunt & Kingstone 2003; Juan, Shorter-Jacobi & Schall, 2004) when attention is covertly detached from overt visual attention (Posner, 1980). Therefore we cannot guarantee on a moment-to-moment basis that point of gaze represents point of attention, but as a general indicator of the state of attention, eye-movements provide a useful measure. Given the role of the task in directing gaze (Hayhoe & Ballard, 2005) it seems unlikely that during tasks such as basketball shooting or driving that a deliberate dissociation of covert from overt visual attention would occur.

Portable eye-tracking allows measurement of eye movements during real world tasks, where it has enabled an understanding of how eye-movements guide natural behaviour (Hayhoe & Ballard, 2005; Land & Hayhoe, 2001). Most portable systems use a pair of glasses with a forward facing scene camera and a reverse facing eye camera (Duchowski, 2017). The position of the eye is determined through corneal reflection and dark pupil tracking. The ASL Mobile Eye glasses (Bedford, MA) use lightweight plastic glasses with a scene camera mounted on top of the frame and an eye camera that reflects an image from an adjustable monocle. This camera projects three harmless infra-red lights into the eye which are reflected back, giving a reference point for the location of the centre of the eye. As light does not escape the pupil, the system detects the black spot, and uses the vector (angle and distance) between this and the corneal reflection to compute the orientation of the eye inside the head.

The device transmits wirelessly to a Dell Latitude laptop installed with Eyevision (ASL) recording software. The software combines the scene and eye recording in real time, giving a circular cursor indicating line of gaze (representing 1° of visual angle) on top of the scene image (accuracy 0.5° visual angle; 0.1° precision). The system is calibrated by asking the participant to fixate markers in the visual field, which are then identified on the laptop, allowing the software to identify point of gaze in relation to the visual scene. This is recorded for offline analysis. This system has been used in a variety of sporting tasks for measuring visual attention and quiet eye in particular (Vine & Wilson; 2010; Harle & Vickers, 2001; Causer, Bennett, Holmes, Janelle & Williams, 2010).

An alternative portable eye-tracking system is the SMI ETG 2.0, which also uses corneal reflection and dark pupil tracking, but measures gaze binocularly. Similarly infra-red lights are reflected from the eye, but in this system eye cameras are mounted within the frame of the glasses below the eye (accuracy 0.5°, resolution 0.1°). The SMI ETG 2.0 records onto an adapted Samsung Galaxy smartphone which can easily be attached to the wearer, allowing free movement. Data is stored on the Samsung phone and later downloaded to a computer for analysis. Calibration across markers in the visual scene is similarly needed with this system, and is done on the smartphone.

The ASL system allows for adjustment of camera and monocle position, but despite this flexibility, difficulties were sometimes encountered with calibration. The SMI system only allows adjustment for the position of the glasses on the head through adding a nose rest. Similarly accurate calibration for some individuals was not possible, based on eye and head shape. All recording were screened before analysis and videos displaying poor calibration or inconsistent recordings were removed from all analyses.

The analysis of quiet eye uses Quiet Eye Solutions Vision-in-Action software (Quiet Eye Solutions Inc., Calgary, CA) which is compatible with the ASL system. Quiet eye solutions allows for coding of action phases and gaze onset/offset using the vision in action paradigm. The gaze-video and side-on video of the shooting motion are first synchronized using markers across both videos. Then the quiet eye fixation can be identified relative to the initiation of the shot phase, defined as the first video frame showing upward motion of the ball to the first frame where the ball left the participant's fingertips, as described by Vickers (1996; see Figure 1.3).

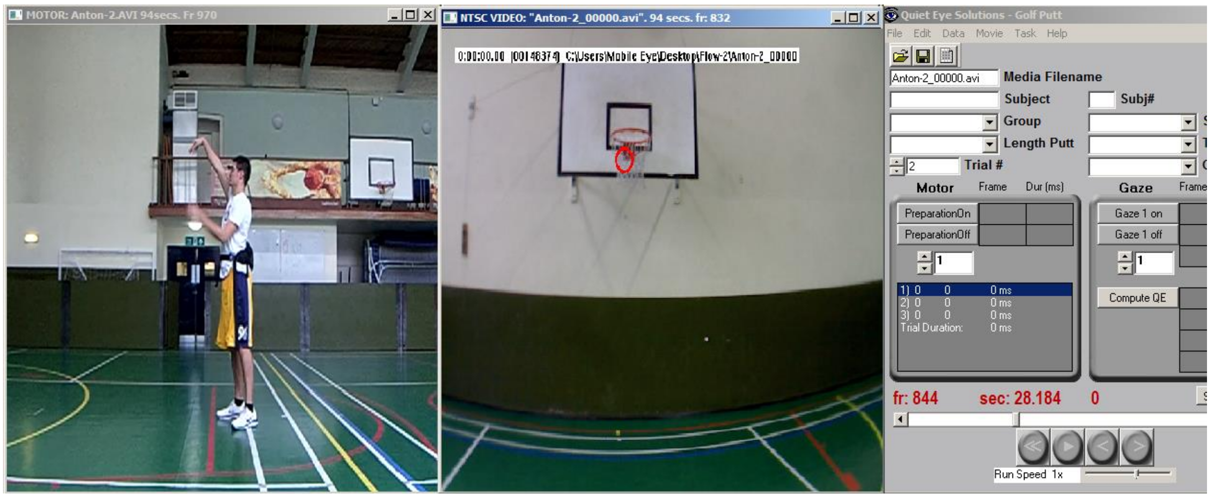

Figure 1.3; Vision in action analysis from Quiet Eye solutions software.

Analysis of gaze data from the SMI system uses proprietary software BeGaze 3.6. BeGaze applies a smoothing algorithm (Salvucci & Goldberg, 2000) to x and y gaze coordinates, then overlays the scene video with point of gaze. This software allows dynamic areas of interest (AOIs) to be drawn onto the gaze video, the software can then determine the number and duration of fixations in the user specified areas. Generalised gaze metrics relating to fixation and saccade frequency and duration can also be exported. Alternatively, raw x-y coordinate data can be extracted from the software, allowing vector based analysis as was done in Chapter 5 (see Figure 1.4).

Figure 1.4; AOI analysis using BeGaze analysis software.

2. Chapter 2 – Studies 1a and 1b

The role of state and trait attention control in flow experience

2.1 Introduction

A central factor in flow that seems to emerge strongly from the work of both Csikszentmihalyi (1975; 1990) and researchers in the sporting domain (Jackson, 1996; Swann et al., 2012) is the intense concentration that is experienced. Attention during flow is often reported as entirely task focused and immune from normal distractors. For example an elite cyclist describes the intense concentration; '*I was totally absorbed, 110 percent…It just amazed me how I could maintain such high concentration for three hours*' (in Jackson & Csikszentmihalyi, 1999, p9.). While reports like this are common, research is yet to examine if there are any measurable attentional benefits present during flow and whether the reported focus is a result of improved attentional control.

Attentional control involves the ability to direct attention to stimuli in the environment most relevant to our current goals (Knudsen, 2007), and reflects the resultant processing from the competitive interaction of two processes; top-down and bottom-up influences on attention. Sarter, Gehring and Kozak (2006) describe top-down control of attentional processing as the 'biasing of attentional resources toward the detection and processing of target stimuli' (p148). Top-down influences would generally benefit sporting performance, as limited attentional resources (Kahneman, 1973) can be directed to task-relevant features of the visuomotor workspace (Memmert, 2009). However bottom-up influences, those coming from innately salient properties of stimuli, have the ability to disrupt top-down control and take up attentional resources (Yantis, 2000; Eysenck et al., 2007). This is particularly the case during anxiety, when stimulus driven effects are amplified, with negative consequences for performance (Eysenck et al., 2007). Descriptions of flow as highly focused attention (Csikszentmihalyi, 1990) suggest a significant influence of top-down influences, and perhaps a reduction in bottom-up influences, as distractors seem to have little effect. In essence, we might expect the opposite attentional effects to anxiety.

Indeed, some findings from computer gaming do suggest measurable changes in visual attention during flow. Jenette et al. (2008) found that during immersion in a computer game (a state similar to flow) participants' search rate decreased as they became more immersed. Conversely, in a non-immersive condition there were significantly more fixations, which also increased over time as attention was redirected to irrelevant stimuli. Similarly, Cheng (2014) found that students exhibited a significantly lower search rate when immersed in an educational computer game, concluding that this reflected them being more focused.

Neuroimaging research has indicated that neural systems associated with top-down, goal-directed processing are indeed activated during flow (Ulrich, et al., 2014; 2016). For instance, Ulrich et al. (2016) found flow in an arithmetic task was associated with increased activity in fronto-parietal areas linked to the multiple demand system (Duncan, 2010), a network for organizing multi-step goal-directed behaviours. Overall it seems likely that when athletes describe becoming highly focused during flow (Jackson & Csikszentmihalyi, 1999), that they are experiencing optimal attention control, this is yet to be directly tested.

Therefore this study aimed to address the role of attentional control during flow in two ways. Study 1a attempted to address whether trait differences in attention control ability were related to propensity to attain flow, using a self-report method. Study 1b aimed to develop a simple experimental manipulation, based on graded goals to extend the findings of study 1a to an objective measure of visual attention control in a sporting task, using the quiet eye (Vickers, 1996).

2.2 Study 1

Whilst flow is mainly discussed as a state variable, Csikszentmihalyi (1990) identifies that individual differences exist in the frequency with which individuals experience flow. He suggests that some individuals seek out instances of challenge and engage in activities for their own sake, making them more likely to find flow. These individuals were identified as having an *'autotelic personality'* (Csikszentmihalyi, 1990; Asakawa, 2004). Twin studies have indicated flow proneness to be moderately heritable (Mosing et al., 2012), and related to Big Five traits emotional stability and conscientiousness (Ullén et al., 2012; Ullén, Harmat, Theorell & Madison, 2016). Research by de Manzano et al. (2013) also suggests that flow may be linked to personality through impulsivity control due to differences in dopamine receptors in the brain. Currently no link has been found between flow proneness and basic cognitive abilities like intelligence or memory (Ullén et al., 2016), although Ullén and colleagues do note that flow proneness might be expected to relate to general cognitive abilities given the relationship between attention and intelligence.

As core features of flow point to the focused concentration experienced during the state (Jackson & Csikszentmihalyi, 1999), individuals who are better able to concentrate, through controlling their attention, may be more prone to experiencing flow. Indeed trait differences do also exist in the ability to control attention (Kane & Engle, 2002; Derryberry & Reed, 2002), which, like flow proneness, is at least partly heritable (Friedman et al., 2008). Kane and Engle (2002) suggest that working memory capacity is largely responsible for attention control, by maintaining relevant goals and screening out distractors. Individual differences in the ability to remain goal-directed were illustrated by

Derryberry and Reed (2002), who found people with higher attention control ability were better able to disengage attention from threatening stimuli. Similarly, Derryberry and Rothbart (1988) found individuals with superior attention focusing and shifting ability were better able to regulate negative emotions like fear, frustration and sadness. In a sporting task, threatening stimuli like opponents or the crowd may interrupt attention through a circuit breaking effect of the stimulus-driven system (Eysenck et al., 2007), but those with higher attention control abilities are better able to maintain a task related (top-down) focus. Therefore individuals with better trait attention abilities may be able to achieve or remain in flow more effectively, leading them to experience flow more often, i.e. displaying high dispositional flow.

Examination of trait rather than state flow was chosen as the starting point for this thesis because long term trends in flow and attention may be more easily detected than state fluctuations, particularly through self-report. Individuals are often poor at reporting internal states, particularly when engaged in a task (Corallo, et al., 2008), so long term tendencies may be more easily identified. Additionally, if effective attention control is important for state flow, this should also be the case for trait flow, as a summation of state experiences. Therefore, in order to provide a full picture of the relationship between flow and attention control, dispositional abilities were examined before moving on to experimental study of state variations.

The additional rationale for this study is that before attempting experimental measurements of attention during flow, it is necessary to understand how strongly general attention abilities relate to dispositional flow. Specifically what degree of variance in dispositional flow is accounted for by attention control ability. The DFS-2 includes items relating to attention, such as '*I had total concentration*' and '*I was completely focused on the task at hand',* but measures additional components of flow. By identifying the relationship between attention control ability and each of the 9 flow dimensions it will be possible to understand if attention control is only related to the experience of concentration, or to all aspects of the experience. Therefore the use of these two self-report instruments helps to develop a nomological network; the interrelationships among concepts of interest. Developing this understanding of how aspects of the flow experience relate to attention forms an important basis for subsequent experimental work in the thesis.

As such, study 1a aimed to investigate the relationship between flow and attention control by assessing whether individuals with higher attention control ability have a higher propensity to find flow in their everyday lives. It was predicted that individuals reporting higher attention control ability would be more prone to flow experience.

2.2.1. Methods

296 (188 male) participants took part in the study (mean age=19.4 years, SD=1.6). All were undergraduate sport science students who voluntarily filled out the questionnaires during lectures. A post-hoc power analysis indicated observed power of 1.00, given alpha=0.05 and the observed effect of R^2= .18.

2.2.1.1 Measures

DFS-2. Trait flow was assessed using the Dispositional Flow Scale-2 (Jackson & Eklund, 2002). The DFS-2 utilises a nine factor structure, corresponding to Csikszentmihalyi's (1990) nine dimensions of flow; challenge-skill balance, clear goals, immediate feedback, sense of control, focused concentration, action-awareness merging, time distortion, loss of self-consciousness and autotelicity. There are 36 items with four loading onto each factor. Each item uses a 5 point Likert scale of agreement (1-*strongly disagree* to 5-*strongly agree*) in reference to questions regarding their tendency to experience flow in their chosen sport. For example; *'I have a sense of control over what I am doing'* and *'I am completely focused on the task at hand'.* The DFS-2 has been validated across cultures (Kawabata, Mallett & Jackson, 2008) and tasks (Wang, Liu & Khoo, 2009; Hamari & Koivisto, 2014), and correlates with motivation, perceived competence and mental toughness in sport and physical activity (Gonzalez-Cutre, Sicilia, Moreno & Fernandez-Balboa, 2009; Crust & Swann, 2013).

ACS. The Attention Control Scale (ACS, see appendix 2) developed by Derryberry and Reed (2002) measures self-reported attention control ability through 20 items loading onto two factors; attentional *focusing* and attentional *shifting*, based on the attentional model of Posner and colleagues (Posner & Petersen, 1990). Items relate to the ability to concentrate and avoid distraction in everyday tasks. Responses to items such as *'I can quickly switch from one task to another'* and *'When concentrating I ignore feelings of hunger or thirst'* are rated on a 1-4 scale representing *'Almost never'* to *'Always'.* The validity of the scale has been supported, with the ACS focusing subscale relating to the ERP P3 amplitude in a Go/No-Go task, and the shifting subscale related to No-Go errors (Wiersema & Roeyers, 2009). Similarly the ACS has shown a small relationship with flanker task performance in the Attention Network Task (Reinholdt-Dunne, Mogg & Bradley, 2013). The factor structure has also been supported across cultures (Olafsson et al., 2011; Fajkowska & Derryberry, 2010).

2.2.1.2 Procedure

Following University ethical approval, lecturers in the Sport and Health Science department were contacted about advertising the study during lectures. As a result, data was collected from four lecture groups across the first, second and third years of a Sport Science program. Details of the study were explained verbally at the start of the lecture, emphasizing that completing the questionnaires was voluntary. Questionnaires, with attached consent form, were then distributed and collected at the end of the lecture, resulting in 296 completed scales.

2.2.1.3 Data Analysis

Missing responses were assessed using Little's Missing Completely at Random test, and values imputed using an expectation maximization procedure. Following this the factor structure of the ACS and the DFS-2 were checked using confirmatory factor analysis. The scale reliability was assessed using Cronbach's alpha. Data was checked for normality before linear regression analyses were used to test whether dispositional attention control predicted dispositional flow and the subscales of the DFS-2. Assumptions of linear regression were checked using residual plots and multicollinearity statistics. Analysis was done using SPSS (v23).

An issue that arises when using multiple self-report instruments that is rarely addressed regards common methods variance (CMV), the variance that is attributable to the measurement method rather than the constructs the measures represent (Podsakoff et al., 2003). For instance, individuals prone to agreeing to items on one scale (acquiescence) will tend to agree with items on another, creating a spurious relationship. To reduce the effects of common methods variance Lindell and Whitney (2001) suggest that a variable with the smallest correlations with its co-variables can be selected as a marker representing overlapping variance due to the measurement method. This variance can then be partialled out of subsequent analyses. As such a marker variable will be used in this way.

2.2.2 Results

For the DFS-2 there were 12 cases missing from 10656 responses (<1%). Little's MCAR test indicated these to be missing completely at random, $X^2(315)=263.30$, $p=.99$. Therefore missing values were imputed using expectation maximization. Cronbach's alpha for the overall scale was .91, with the nine individual scales, challenge-skill balance (.82), action-awareness merging (.80), clear goals (.79), immediate feedback (.91), concentration (.85), control (.83), self-consciousness (.87), and autotelicity (.81) all showing high reliability.

For the ACS, there were 18 cases missing from 5920 responses (<1%). Little's MCAR test indicated these cases to be missing at random, $X^2(82)=91.06$, $p=.23$. Therefore missing values were imputed using an expectation maximization algorithm. Cronbach's alpha showed good overall scale reliability (0.82).

Following Lindell and Whitney (2001), in order to account for CMV a variable with low correlation can be selected to be used as a covariate, representing the effect of common methods bias. The variable '*Time distortion*' was selected, as it had had low correlations with overall ACS and DFS-2 scores. Podsakoff et al. (2003) suggest that a pre-selected variable can be used to account for CMV. The selection of '*Time distortion*' was post-hoc, but otherwise follows this recommendation. As such, in regression models this variable was entered first (block 1) to account for CMV, so all reported effects represent the *remaining* variance explained (block 2).

An linear regression indicated total ACS score to significantly predict overall trait flow, β=0.78, $F(1,292)=63.34$, $p<.001$, $R^2=.18$.

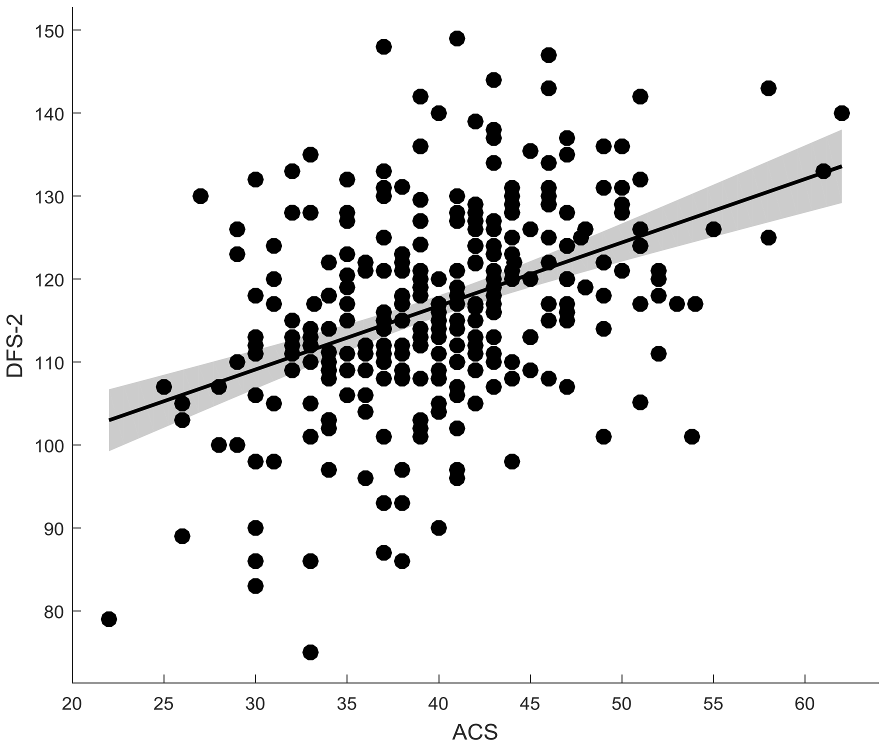

Figure 2.1; Regression (with 95% confidence intervals) of DFS-2 onto ACS.

Further linear regressions were run to examine whether overall attention control ability significantly predicted each of the flow scale dimensions (see table 2.1).

Table 2.1; Linear regression for each DFS-2 dimension on ACS total.

Dimension	R^2	*Significance* (p)	β
Challenge skill balance	.06	<.001*	0.08
Action-awareness merging	.02	0.008*	0.05
Clear goals	.07	<**.001***	0.1
Immediate feedback	.01	0.09	0.05

Concentration	.13	<**.001***	0.14
Control	.12	<**.001***	0.12
Self-consciousness	.06	<**.001***	0.12
Autotelicity	.07	<**.001***	0.09
Time Distortion	.00	.75	-0.05

***Significant at p<.05**

2.2.3 Discussion

Athletes in flow describes an intense focus, where they are wholly task focused and immune to distraction (Jackson & Csikszentmihalyi, 1999), suggesting a state of attention control where the top-down system biases processing to relevant stimuli, with little impact of the stimulus driven system (Knudsen, 2007; Corbetta & Shulman, 2002). Based on these descriptions of flow experience and the autotelic personality it was predicted that individual attention control ability (ACS) would be related to dispositional flow (DFS-2). This relationship was supported with overall ACS scores accounting for 18% variance in DFS-2 scores (after controlling for CMV).

When examining the individual scales of the DFS-2 '*Concentration'* and '*Sense of control'* showed the strongest relationships with the ACS. 'Concentration' would be expected to show the closest relationship, but all factors except '*Immediate feedback'* and '*Time distortion'* were significantly related. While these results indicate a relationship between attention control ability and dispositional flow, a large proportion of variance is unaccounted for. For comparison, Crust and Swann (2013) found self-reported mental toughness to share 42% variance with the DFS-2 (although CMV was not discussed). As such, additional factors like the Big Five personality traits (Ullén et al., 2016) intrinsic motivation and challenge seeking (Csikszentmihalyi, 1990; Asakawa, 2004) are likely to contribute to the autotelic personality in addition to attention control ability.

While one of the issues with self-report scales was addressed (common methods variance), the use of subjective ratings still presents challenges due to reporting biases. Particularly when measuring attention it is unclear whether individuals can reliably report states of absorption (Brewer et al., 1991). The ACS has been shown to relate to objective measures of attention (Wiersema & Roeyers, 2009), but some studies have found this to be a weak relationship (Reinholdt-Dunne et al., 2013). As such these results provide tentative evidence for the role of attention control in flow, but clearly further investigation using objective measures is required.

2.2 Study 1b

Based on the findings of study 1a, flow may be related to attention control ability, but more objective measures are required to assess the potential relationship. The aim of study 1b was to address this issue by using an experimental approach with objective measures of visual attention control, namely the gaze strategy, quiet eye (Vickers, 1996). Additionally, to develop the findings from study 1 regarding trait attention abilities, an alternative self-report measure of attention was chosen: dispositional mindfulness (Brown & Ryan, 2003). This was used to assess whether mindful individuals were more prone to flow experience in a sporting task, and whether they demonstrated more focused visual attention.

In order to provide an objective measure of visual attention control, study 1b assessed gaze behaviour in a basketball-shooting task. If participants experience an enhanced control of attention during flow, we would expect visual attention to be task-focused and unaffected by stimuli irrelevant to the current performance. This can be assessed in a sporting task through analysis of eye movements, which are crucial for athletic performance (Abernethy, 1991). Additionally, visual attention is known to strongly reflect the allocation of general attention due to closely overlapping neural structures (Corbetta et al., 1998; Vickers, 2009). An instance of visual behaviour indicative of attention control in a sporting task is the quiet eye (QE; Vickers, 1996). Quiet eye is defined as the final fixation or tracking gaze before movement execution, directed to a single location or object within 3° of visual angle for a minimum of 100ms (Vickers, 1996; 2007). A longer QE duration has been linked with expertise and superior performance across a range of interceptive and far aiming tasks (see Lebeau et al. 2016 for a recent meta-analysis) and reflects an efficient top-down control of attention (Vine & Wilson, 2011). Research demonstrates that QE duration differs between experts and non-experts (Mann et al., 2007), and is important for maintaining performance under the disruptive effects of anxiety (Wilson, Vine & Wood, 2009). Therefore the length of quiet eye durations may provide an objective marker of visual attention control during flow.

The construct of mindfulness links strongly to both attentional control and flow (Kee & Wang, 2008), and may provide an alternative measure of attention ability, given the relatively weak relationship found in study 1a. John Kabat-Zinn (1994, p.4) describes mindfulness as ‘paying attention in a particular way: on purpose, in the present moment, and non-judgmentally’. The capacity to become mindful is cultivated through various meditation techniques, while more recently mindfulness has been adapted from Buddhist meditation practices for use in the west, with much clinical success (Baer, 2003; Brown & Ryan, 2003; Hofmann et al., 2010). Self-report measure of mindfulness have been widely used in clinical research (Carlson & Brown, 2005; Shapiro, Oman, Thoresen, Plante & Flinders, 2008; Grossman, 2008) with self-report scales found to be predictive of improved responses to stress and psychological wellbeing (Brown & Ryan, 2003; Arch & Craske, 2010). As mindfulness measures have been validated over more studies than the ACS (Grossman, 2008) they may provide a more reliable metric, but one which nonetheless reflects similar attention control abilities (Bishop et al., 2004).

Bishop et al.’s (2004) description of the essential components of mindfulness as self-regulation of attention, sustained attention, attention switching and inhibition of elaborative processing highlights the overlap with attention control. This is supported by findings that mindfulness training can benefit attention control ability (Jha, Krompinger & Baime, 2007; Chambers, Chuen Yee Lo & Allen, 2008; Wenk-Sormaz, 2005). Brefczynski-Lewis, Lutz, Schaefer, Levinson and Davidson (2007) even found participants to have more efficient allocation of attention, with less overt effort, a finding particularly relevant given the ease of performance reported during flow (Csikszentmihalyi & Nakamura, 2010). Research by Kee and Wang (2008) indicates that mindfulness may be related to flow, as individuals high in mindfulness were found to have a dispositional tendency for flow. Additionally, initial findings regarding the benefits of mindfulness for training flow further suggests that the two states may be linked (Aherne, Moran & Lonsdale, 2011; Kaufman, Glass & Arnkoff, 2009). Therefore, as study 1a indicated a relatively weak relationship between the ACS and flow, mindfulness will be investigated here as an alternative measure of trait differences in attention. Further, if individuals higher in mindfulness exhibit greater flow experience it will provide additional evidence for future flow training applications.

As the findings of study 1a are purely correlational, like much flow work to date, a secondary aim of this experiment, and the thesis in general, was to develop an experimental approach to assessing flow in sport. Experimental approaches to date have focused on manipulations of the challenge of the task. For instance Keller and Bless (2008; also Keller, et al., 2011) developed an experimental approach to flow by manipulating the difficulty of a 'Tetris' style game. More recently Tozman et al. (2015) also utilized varying levels of difficulty to create an experimental manipulation in a driving simulator.

However, experimental approaches have not been transferred to a sport setting, where research has relied on qualitative correlational methods (Jackson, 1992; Swann et al., 2015). If we are to move beyond our current understanding of flow, and investigate attentional mechanisms, experimental approaches are required. Therefore a secondary aim of this study was to test the effectiveness of an experimental manipulation of perceived challenge through providing task goals. Basketball free throw shooting was chosen for the experimental task, as it has established procedures for assessing the QE (Vickers, 1996), has been used previously in flow research (Pates, Cummings & Maynard, 2002), and afforded experimental instructions that could create a challenge-skill balance.

In summary, the principal intention of study 1b was to investigate whether the experience of flow leads to measurable changes in visual attentional control. Consequently eye movement data was collected during a basketball free throw task in response to a manipulation of perceived challenge through setting clear goals. Instructions to promote perceived challenge were chosen to create flow and no-flow conditions to allow experimental comparison. Additionally, to develop our understanding of trait differences in propensity to attain flow, mindfulness scores were used to group participants into high and low attention abilities. Firstly it is predicted that participants will experience greater flow and exhibit better visual attention control and performance in conditions designed to provide challenging goals. Additionally it is predicted that individuals high in mindfulness will be more likely to experience flow in the experimental task.

2.2.1 Methods

2.2.1.1 Participants

Power analysis using G*Power 3.1 (Faul, Erdfelder, Lang & Buchner, 2007) indicated that at least 20 participants were required to achieve a power of 0.95 (alpha=0.05), based on an effect size of η^2=.45 from Tozman et al. (2015). Accordingly, twenty-six participants (15 female) volunteered to take part in the study, all were undergraduate students who were not regular basketball players. 117 participants initially completed the Mindful Attention Awareness Scale (Brown & Ryan, 2003), with those scoring a standard deviation above or below the median contacted for further participation. Due to the stringent criteria and to aid recruitment, some participants with scores closer to the median were later contacted for participation as well. Participants were not aware that they had achieved a particular score on the questionnaire. Participants attended testing individually, and signed consent forms, with details of the study explained to them verbally and in writing. University ethics committee approval was obtained prior to participant recruitment.

A post-hoc power analysis based on the sample of 26 participants indicated observed power of 0.31, given alpha=0.05 and the observed effect of ω^2= .046 (η^2=.09). However, observed power displays a direct relationship with the significance value and degrees of freedom, such that any non-significant effect (i.e. alpha greater than .05) will display low observed power (Lenth, 2007).

2.2.1.2 Apparatus

Free throws were taken at a standard net, at a reduced height (2.25m) and from a reduced distance (3.50m) due to the ability of the participants. Gaze was measured using an ASL (Applied Science Laboratories; Bedford, MA) Mobile Eye Tracker, which comprises a pair of glasses which carries a forward facing scene camera and an eye camera, both recording at 30Hz. The eye camera detects the dark pupil plus three infra-red lights reflected off the cornea to calculate the point of gaze in real time. The glasses are attached to a mobile recording unit (Mobile Eye XG) that is worn in a pouch on the back, allowing relatively free movement. The recording unit projects wirelessly to a laptop (Dell latitude) installed with Eyevision (ASL) recording software. A circular cursor, representing 1° of visual angle, indicates point of gaze on top of the scene image (±0.5° visual angle; 0.1° precision). This was recorded for later analysis.

The motor phase was recorded with a digital camera (Casio Exilim EX-Z850, 33fps) positioned to the right and in front of the participant, to record the whole shooting movement. The experimenter was positioned to the side, away from the participants' line of sight.

2.2.1.3 Measures

Mindfulness. The Mindful Attention Awareness Scale (MAAS, Brown & Ryan, 2003, see appendix 3) is a 15 item questionnaire designed to measure dispositional mindfulness through attention to and awareness of what is happening in the moment. Questions take the form; '*I find myself doing things without paying attention*' with a six point Likert scale for agreement (1- *almost always* to 6- *almost never*). Items load onto a single factor, with higher mean scores indicating a higher degree of mindfulness. This scale has been used widely in mindfulness research (eg. Shapiro et al., 2008; McCracken, Gauntlett-Gilbert & Vowles, 2007), with Sauer et al. (2013) finding that the MAAS has strongest predictive validity among mindfulness scales.

Flow. Sate flow was assessed with the Flow State Scale-2 (FSS-2, Jackson & Eklund, 2002, see appendix 4), the state equivalent of the DFS-2 used in study 1a. The FSS-2 is designed to assess flow experiences during a particular activity, with data collected immediately after completion of the activity. The FSS-2 utilises a nine factor structure, corresponding to Csikszentmihalyi's (1990) nine dimensions of flow. There are 36 questions with 4 loading onto each factor. Each question uses a 5-point Likert scale of agreement (1-*strongly disagree* to 5-*strongly agree*) in reference to questions like; *'I had a sense of control over what I was doing'.* The FSS-2 has been used widely in sport research (Vlachopoulos et al., 2000) and across cultures (Calvo et al., 2008).

Quiet Eye period. Based on previous research (Vickers, 1996; Wilson, Vine & Wood, 2009), key gaze locations were defined as the rim of the basket, the rectangle behind the basket and the net, to the line of the bottom of the backboard. Fixations outside of this location were not considered important for quiet eye. The quiet eye period is the final fixation directed to a single location in the visuomotor workspace, within 3° of visual angle, for a minimum of 100ms (3 frames). The onset of the quiet eye begins at the initiation of the final fixation made before the final movement occurs, with an offset when the gaze fixation deviates from the location by 3° of visual angle or more for 100ms (Vickers, 2007). If the fixation deviates for one or two frames and returns to the original location, the quiet eye is coded as continuing. For the basketball free throw the final movement was coded as the final extension of the arm prior to release, effectively the first video frame where the angle between the upper and lower arm increases (Vickers, 2007).

Performance. A simple percentage shooting score (number of successful shots x 100/number of unsuccessful shots) was calculated from the 50 shots in each condition.

2.2.1.4 Procedure

After receiving the participant information sheet and signing the consent form, participants were fitted with the ASL eye tracker. To calibrate the eye tracker participants were required to look at tape markings on the backboard of the basketball hoop. Participants were given 20 shots to familiarize themselves with the task and with the equipment. This was also used to check the recording and calibration of the eye-tracker.

Participants performed two blocks of 50 free-throws, one with flow instructions and one with neutral instructions. The order of the blocks was counterbalanced across participants. Based on Csikszentmihalyi's (1990) key task components of challenge-skill balance, clear goals and immediate feedback, the manipulation instructions aimed to create these conditions in only one condition. In the flow condition participants were asked to score three baskets in a row, then four in a row, and so on. In attempting to beat their own score, participants should create their own challenge-skill balance, have a clear goal and receive immediate feedback. No-flow instructions required participants to take shots at the basket, without providing any particular goal or challenge.

Participants then took 50 throws in their own time, with the gaze being recorded by the eye tracking glasses and shooting movement being recorded on a separate digital camera. The two recordings were synchronized using a clacker board, which could be detected by both the eye tracker camera and the external camera. The experimenter monitored the recording of these, with recalibration taking place during the trial if necessary. After 50 shots participants sat and filled out the FSS-2 questionnaire. They then completed the second condition and the FSS-2 again.

2.2.1.5 Data Analysis

Gaze and movement data were analysed using Quiet Eye Solutions software (Quiet Eye Solutions Inc.). This allows gaze and motor videos to be time locked showing vision in action (see Figure 2.2), the motor video on the left, allowing coding of the final movement and the gaze video on the right, with the red circle displaying centre of gaze (1° of visual angle). Quiet eye duration was calculated for 40 of the 50 shots taken by each participant, excluding the first ten to allow participants to settle in.

2 (group) x 2 (condition) mixed ANOVAs were run to examine the effect of high/low mindfulness (group) and flow instructions (condition) on performance and FSS-2 scores. A 2 (group) x 2 (condition) x 2 (success) mixed ANOVA was run on QE durations to additionally examine whether QE duration was longer in successful shots. Violations of sphericity were addressed using a Greenhouse-Geisser correction. Significant interactions were followed by post-hoc Bonferroni corrected t-tests.

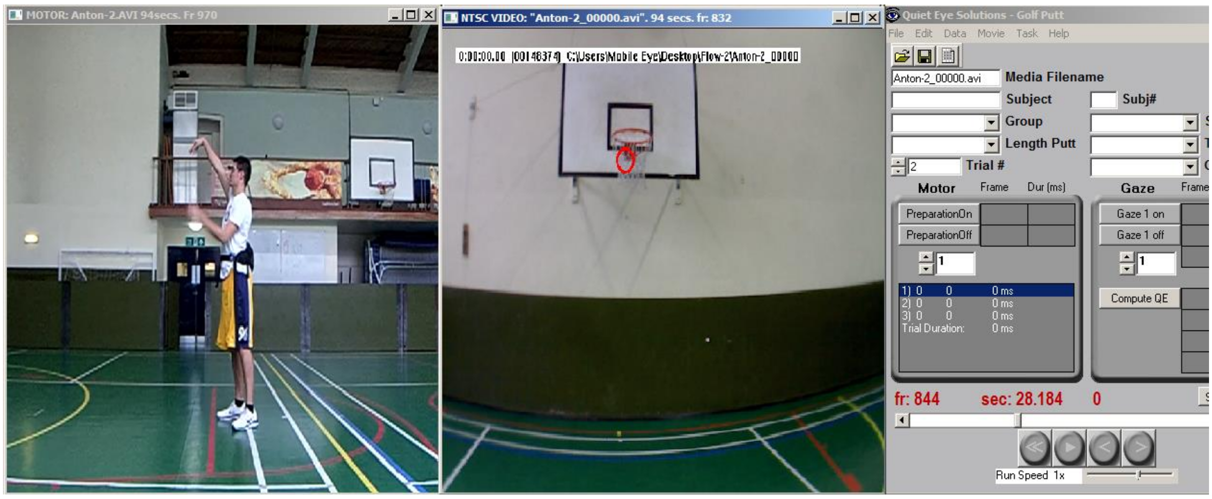

Figure 2.2; Vision in action analysis from Quiet eye solutions software. From left to right; Panel A shows the motor video, Panel B shows point of gaze video from ASL eye-tracker, and Panel C shows the frame counter.

2.2.2 Results

2.2.2.1 MAAS

A reliability analysis of the MAAS showed a Cronbach's alpha of 0.84 for the single factor, with Brown and Ryan (2003) reporting internal consistency around 0.85. To check that mindfulness groups were significantly different from each other an independent t-test was run, confirming that there was a difference between High (N=11, M=66.64, SD= 6.67) and Low (N=15, M=46.00 SD=5.49) groups, $t(24)$=8.65 p<.001, d=3.434.

2.2.2.2 FSS-2

The reliability of the nine subscales of the FSS-2 were checked using Cronbach's alpha (see Table 2.2 below). Values were in an acceptable range from 0.76 to 0.93, as compared to Jackson and Eklund's (2002) original reliability alphas ranging from 0.80 to 0.90.

Table 2.2; Cronbach's alpha scale reliability scores

Subscale	Flow condition	No-flow condition
Challenge-skill balance	0.92	0.81
Action-awareness merging	0.92	0.88
Clear goals	0.78	0.88
Immediate feedback	0.89	0.92
Concentration	0.90	0.92
Sense of control	0.91	0.90
Loss of self-consciousness	0.76	0.93
Distortion of time	0.84	0.84
Autotelic	0.90	0.85

To assess the effect of flow/no-flow instructions and high/low mindfulness on flow experience a 2x2 mixed ANOVA on FSS-2 scores was conducted. There was found to be no significant difference between Flow (M=126.35, SD=18.53) and No-Flow conditions (M=130.42, SD=16.63), $F(1,24)=2.21$, $p=.15$, $\omega^2= .046$. There was no significant difference between high MAAS (M=132.55, SD=15.11) and Low MAAS (M=125.33, SD=16.28) groups, $F(1,24)=1.32$, $p=.26$, $\omega^2=.012$ and no interaction, $F(1,24)=0.75$, $p=.40$, $\omega^2=.000$.

2.2.2.3 Performance

To assess the effect of flow/no-flow instructions and high/low mindfulness on performance a 2x2 mixed ANOVA on shooting percentage was conducted. There was found to be no effect of flow condition, (Flow M=49.08, SD=10.04, No-Flow M=48.77, SD=11.95), $F(1,24)=0.03$, $p=.87$, $\omega^2=.000$. There was also no effect of MAAS (High M=49.66, SD=10.00, Low M=48.40 SD=8.76) on performance, $F(1,24)=0.11$, $p=.74$, $\omega^2=0.000$ and no interaction, $F(1,24)=0.07$, $p=.79$, $\omega^2=.000$.

A linear regression indicated that flow scores did not significantly relate to shooting performance overall, $\beta=0.15$, $F(1,50)=3.21$, $p=.08$, $R^2=.06$. However when conditions were analysed separately, there was a significant relationship in the no-flow condition, $\beta=0.36$, $F(1,24)=7.98$, $p=.009$, $R^2=.25$ but not the flow condition, $\beta=-0.01$, $F(1,24)=0.004$, $p=.95$, $R^2=.00$.

2.2.2.4 Quiet Eye duration

A reliability check for coding procedures showed intra-rater reliability to be acceptable (R=.90) (Thomas, Silverman & Nelson, 2015).

A 2 (group) x 2 (condition) x 2 (success) mixed ANOVA on QE duration showed a significant effect of flow condition, (Flow; M=1086.89, SD=576.93, No-Flow; M=801.04, SD=429.92), $F(1,14)$=8.02, p=.01, ω^2=.304. However there was no significant effect of MAAS (High M=1058.28, SD=351.20; Low M=829.65 SD=563.96), $F(1,14)$=0.95, p=.35 ω^2=.020, and no significant effect of success (Hits M=964.40, SD=476.94 versus Misses M=923.54, SD=470.05), $F(1,14)$=1.49, p=.24, ω^2=.029. There were no significant two-way or three-way interactions (ps>.42; see Figure 2.3).

Over both conditions a linear regression showed that there was a trend for QE duration to relate to performance (%), β=0.01, $F(1,30)$=3.44, p=.07, R^2=.10. Examining the conditions separately indicated that during the flow condition QE was marginally related to shooting performance, β=0.01, $F(1,14)$=5.46, p=.04, R^2=.28, but not in the no-flow condition, β=0.01, $F(1,14)$=0.42, p=.53, R^2=.03.

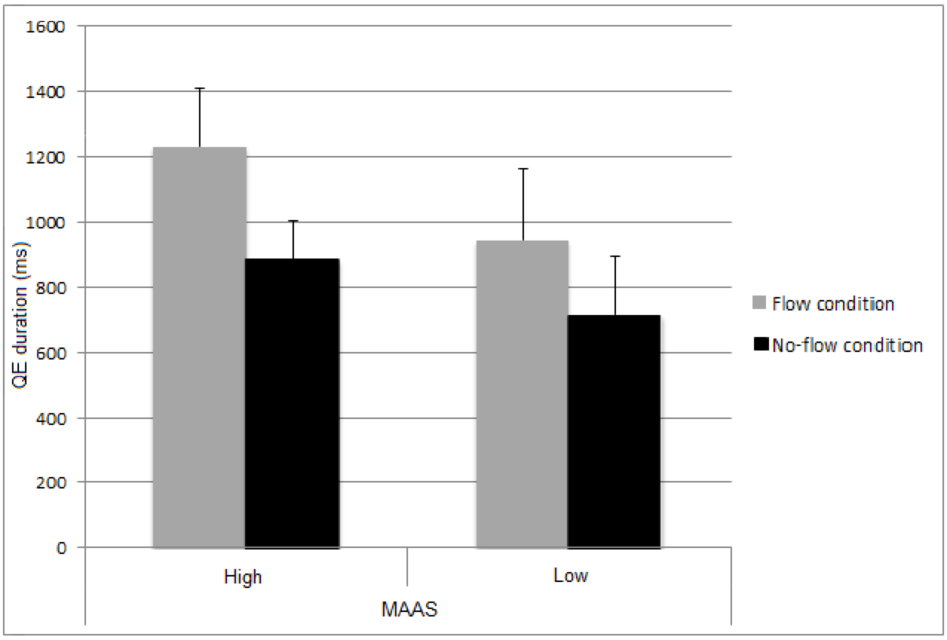

Figure 2.3; Mean (and standard deviation) quiet eye duration (ms) for MAAS groups in flow and no-flow conditions.

2.2.3 Discussion

The aim of study 1b was to investigate whether flow experience was related to improved control of visual attention, measured through QE duration. Flow theory describes the state as one of complete absorption and immunity to distraction (Jackson & Csikszentmihalyi, 1990) and as such we might expect to see effective gaze control. Some studies have indicated that this may be the case (Jenette et al., 2008; Cermakova, Moneta & Spada, 2010; Cheng, 2014) but the hypothesis has not been directly tested. A relationship between flow and gaze control would explain some of the performance advantages (Jackson et al., 2001; Koehn & Morris, 2012), and contribute to an understanding of the cognitive mechanisms responsible for flow. Additionally, it may provide insight into the QE phenomenon, in particular how changes in QE duration may relate to peak performance states.

Contrary to our hypotheses, there was no difference in flow experience as a result of the flow instructions. There was, however, a longer QE ($p=.01$, $\omega^2=.304$). Whilst in line with our prediction that the flow condition would exhibit longer QE, this cannot be interpreted as support for improved attention control during flow, as no corresponding difference in flow experience was found. This increase in QE is potentially a result of motivating factors in the flow instructions, with the increased challenge eliciting greater effort. For instance Walters-Symons et al. (2017) found longer QE durations when participants faced a greater perceived challenge, and suggest that the QE increase may have reflected additional investment of effort. Therefore it cannot be concluded that the QE changes are a result of flow experience.

The experimental manipulation employed here was somewhat exploratory, in an attempt to develop manipulations that could be used in sporting scenarios. The failure to find a significant difference between flow conditions may be attributable to either the instructions given or the skill of the participants. The instructions were intended to provide structure for participants to find challenge, to provide clear goals and allow performance feedback in line with Csikszentmihalyi's (1990) flow theory. However the additional pressure to continually beat your best run may have created anxiety in some individuals, which can disrupt flow (Koehn, 2013). Alternatively, as participants were not skilled basketball players, their ability may have prevented them achieving flow, regardless of the task instructions. Research indicates that flow is more likely in experts (Canham & Wiley, 2003) potentially due to the tendency for automatic processes to take control of movement (Wolf et al., 2015). The novices in this study may have been prevented from reaching higher levels of flow due to their need to consciously focus on the skill (Deeny et al., 2003). As a result, achieving flow may have been less likely.

A secondary hypothesis was that individuals scoring highly on the MAAS would experience greater flow in the basketball free-throw task, due to their ability to focus their attention. Mindful individuals have previously been found to display a greater propensity for flow (Kee & Wang, 2008), but here no difference was found between groups. Given previous findings linking mindfulness and flow (Aherne, Moran & Lonsdale, 2011) and the relationship between individual attention ability and flow experience found in study 1a this is perhaps surprising. However, previous findings relate to more long term trends in flow experience, rather than a one-off instance. The effect of trait attention ability may not be sufficient to see measurable changes in a single task, and future studies may require repeated measurements over time to replicate this effect.

A curious finding relates to the QE-performance relationship found here. While this was not a direct prediction of the study, the beneficial effect of a longer quiet eye in the basketball free-throw is well established (Vickers, 1996; Wilson, Vine & Wood, 2009). This relationship was found to be strong in the flow condition (R^2=.28, although p=.04), but absent in the no-flow condition. The reason for this is unclear, but the high degree of variability in the QE of the novices may have influenced our ability to detect QE effects (for instance mean QE = 943.97, SD = 503.43).

The major limitation of this study relates to the experimental manipulation, as other findings were difficult to interpret in light of the null effect. While based on Csikszentmihalyi's (1990) task dimensions, the instructions had little influence on flow experience. Previous gaming research has altered the objective difficulty of the task (Keller & Bless, 2008), whereas we attempted to change only the perceived challenge, so as to avoid confounding task difficulty effects on QE (Williams, Singer & Frehlich, 2002; Walters-Symons et al., 2017). Future studies should continue to develop experimental manipulations, where control of the challenge-skill balance appears to hold greatest promise (Fong, Zaleski & Leach, 2015), but may require a stronger influence on perceptions of challenge. Alternatively, a flow/no-flow approach may have been overly simplistic, and an approach using graded goals in order to find the optimal challenge for each individual may be more appropriate. To do this, a short form flow measure may be needed to guard against questionnaire fatigue. Additionally, subsequent research may wish to examine similar measures of visual attention in expert players, given their reduced need for conscious control (Deeny et al., 2003) and greater ability to find flow (Canham & Wiley, 2003).

2.3 General discussion

In summary this study aimed to investigate a potential relationship between flow experience and attention control ability, both through self-reported trait measures and objectively measured state differences in visual behaviour. The investigation of cognitive changes, like visual attention control, are crucial for advancing our understanding of proximal flow mechanisms, and ultimately how these mechanisms can be targeted for practical applications.

Study 1a identified that a relationship exists between trait level attention control abilities and dispositional flow. The relationship can be considered relatively weak, indicating that a flow disposition, the 'autotelic' personality (Csikszentmihalyi, 1990), likely has additional factors, like intrinsic motivation and challenge seeking (Csikszentmihalyi, 1990; Asakawa, 2004). Study 1b aimed to further test the role of attention abilities, by comparing whether individuals with good attention abilities (measured through mindfulness) were likely to find flow in a specific sporting task. Additionally we aimed to move from a subjective measure of attention control to an objective measure, in the form of quiet eye duration. There was no evidence that highly mindful individuals experienced more flow, or that flow was linked with improved control of visual attention.

However, given the difficulties encountered in providing an experimental manipulation of flow, and the findings from study 1a, further investigation is required to determine whether the null effects were purely due to experimental difficulties.

2.4 Interim summary

The findings from Chapter 2, study 1a provided initial evidence of a relationship between attention control ability and propensity to experience flow. This relationship between attention and flow was not supported in study 1b, however, possibly due to issues with the experimental manipulation. As one of the overarching aims of the thesis is to develop experimental methods in sport, Chapter 3 aims to improve upon the approach of Chapter 2 to further investigate quiet eye as a marker of visual attention control during flow in a sporting task. The principal changes in methodology relate to the use of more experienced performers, a more graded approach to providing challenges in the sporting task and an alternative, short form flow measure to allow more frequent measurement of flow experience.

3. Chapter 3 – Study 2

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Flow and quiet eye: the role of attentional control in flow experience

3.1 Introduction

The previous study (1b; Chapter 2) aimed to assess the relationship between flow and visual attention control in a far aiming task. A manipulation of perceived challenge was employed, to examine the effect on self-reported flow and visual attention (quiet eye). There was, however, no effect of the manipulation on flow. Therefore the primary aim of the current study was to develop the experimental approach to flow research in sport, through improving on the methodology of study 1b (Chapter 2). The secondary aim of the current study was to further examine the relationship between flow and control of visual attention, as in study 1b (Chapter 2), through changes in quiet eye.

To study flow experimentally, it is necessary to create the conditions for flow to occur. Lab-based experimental approaches have been utilised within gaming research by manipulating the challenge-skill balance (Keller & Bless, 2008), identified by Nakamura and Csikszentmihalyi (2002) as a crucial precursor to flow. Csikszentmihalyi's (1975) flow theory predicts that flow occurs when there is a perceived balance between challenge and skill. If the task is too easy (skills outweigh challenges) then boredom or apathy occurs, but if the task is overly difficult (challenges outweigh skills) the individual feels stress or anxiety. Controlling this balance provides the best route to manipulating flow (Moller et al., 2010), but is yet to be applied in sporting tasks.

Based on this role for the challenge-skill balance, study 1b (Chapter 2) attempted to induce variations in flow through providing a self-referenced challenge in one condition, and little challenge in the other. In order to develop this approach, the current study provides a range of levels of challenge, to allow participants to find their optimal fit, rather than a binary flow/no flow approach. To achieve this, shooting goals ranging from too easy to too difficult (for

University level players) were chosen, providing 5 different levels of challenge. While the early work of Csikszentmihalyi (1990) focuses on the objective balance of task demands and skills of the individual, other researchers suggest that the perception of challenge is also important (Engeser & Schiepe-Tisak, 2012). The provision of a range of goals may serve to change this perception of challenge. Goal-setting theory (Locke & Latham, 2013) outlines how goals motivate and direct behaviour, and allow evaluation of personal functioning. It is proposed that people work harder for more challenging goals and that goals direct attention. In particular specific, challenging goals are thought to maximise performance. Providing participants with a range of goals is therefore intended to provide a goal that is individually challenging, leading to effort, engagement, attention and a perception of optimal challenge that is conducive to flow.

In line with this decision to use a range of levels of perceived challenge, a shorter flow measure is also employed, to allow more frequent measurement while avoiding fatigue. The Flow Short Scale (Rheinberg, Vollmeyer & Engeser, 2003) utilises two subscales, *Absorption* and *Fluency,* which reflect a view that core features of flow are task absorption and smooth, proficient task performance. In comparison to the FFS-2 (Jackson & Eklund, 20002) employed previously, this scale places less emphasis on flow as a positive experience, but focuses on the absorption in the optimally challenging task. A longer version of this scale is available (Engeser, 2012), but was not utilised here as scale brevity was important. Additionally, expert performers are used in this study, as proficiency in the task may enable greater flow experience (Canham & Wiley, 2003), and the use of novices in study 1b lead to a high degree of variability in QE durations. Therefore this study reflects a development of the experimental approach used previously, to better examine the relationship between flow and attention control, in line with the overall aims of the thesis.

While those in flow describe a heightened task focus and prolonged concentration (Jackson & Csikszentmihalyi, 1999) indicative of optimal attentional control, this is yet to be measured empirically. Initial support comes from the computer gaming literature, where immersion in the task (a state similar to flow[3]) has been characterised by efficient control of visual attention (Cheng, 2014; Jenette et al., 2008). Additionally, recent neuroimaging research has implicated the role of higher order attentional processes in the flow experience (Ulrich, Keller & Grön, 2016). The efficient control of top-down visual attention is also linked to superior performance in sporting tasks (Mann et al., 2007) with the quiet eye (QE; Vickers, 1996) providing an objective index of optimal visual attentional control. A longer QE duration has been linked with expertise and superior performance across a range of interceptive and far aiming tasks (see Lebeau et al. 2016 for a recent meta-analysis) and reflects an efficient top-down control of attention (Vine & Wilson, 2011). Therefore, in line with study 1b (Chapter 2) quiet eye will be used as an index of attentional control in a far aiming task.

In summary, this study aimed to further understand the relationship between changes in visual attention and flow, through a development of the experimental paradigm used in study 1b (Chapter 2). To achieve this, the effect of a range of goals on flow and QE were examined in a far aiming task. It was predicted that moderate goals will present an optimal challenge, making flow more likely. It was also predicted that moderate goals, would lead to more focused visual attention, indexed by longer quiet eye durations.

3.2 Methods

3.2.1 Participants

Power analysis using G*Power 3.1 (Faul, Erdfelder, Lang & Buchner, 2007) indicated that 32 participants were required to achieve a power of 0.95 (alpha=0.05), based on Cohen's f = 0.25 from Cheng (2014). Correspondingly, eighteen basketball players (2 female; M_{age} = 23.88 years; SD = 7.56; mean experience = 10.8 years; SD=7.75) and seventeen netball players (all female, M_{age} = 20.00 years; SD = 0.97; mean experience = 11.50 years, SD=2.10) were recruited. All participants attended testing individually, and signed consent

[3] The state of immersion refers to being fully present and absorbed in an experience (particularly during gaming). It differs from flow in that it can be passive (such as TV viewing) whereas flow requires an active engagement with the task.

forms, with details of the study explained to them verbally and in writing. University ethics committee approval was obtained prior to participant recruitment.

A post-hoc power analysis based on the sample of 32 participants indicated observed power of 0.57, given alpha=0.05 and the observed effect of ω^2= .023 (η^2=.052). This is a comparatively high level of power for a non-significant effect (Lenth, 2007).

3.2.2 Apparatus

For the basketball task, free throws were taken at a standard net, at NBA regulation height (3.05m) and distance (7.24m), with a regulation basketball. For netball, shots were taken at a standard netball post, at a height of 3.05m, as recommended by England Netball. There is no netball equivalent of the basketball free-throw. Therefore a shooting distance of 3.2m was chosen based on previous use in flow research (Pates et al., 2003) and discussion with netball players who identified it as a typical but challenging shooting distance.

Participants' eye movements were recorded using an ASL (Applied Science Laboratories; Bedford, MA) Mobile Eye Tracker, which comprises a pair of glasses carrying a forward facing scene camera and an eye camera using dark pupil tracking (±0.5° visual angle; 0.1° precision), recording at 30Hz. Shot mechanics were recorded with a digital camera (Casio Exilim EX-Z850, 33fps) positioned at a right angle to the participant, to record the whole shooting movement.

3.2.3 Measures

Flow. State flow was measured using the Flow Short Scale (FSS, Rheinberg, Vollmeyer & Engeser, 2003, see appendix 5), a questionnaire widely used in gaming research (Engeser & Rheinberg, 2008). This short measure was chosen as repeated administrations of long measures may have induced fatigue. This scale also provides a simple unitary measure, reflecting the goal of identifying flow rather than investigating aspects of the experience. The FSS measures flow through ten questions scored on a 7-point Likert scale, loading onto two factors, absorption in the activity and fluency of performance, or alternatively a global flow factor. Statements such as '*I feel just the right amount* *of challenge*' are rated for accuracy, with responses ranging from '*Very much'* to *'Not at all'.* Note, lower scores on this scale reflect higher felt flow. A reliability analysis gave Cronbach's α of .86 for the overall scale.

Quiet eye period. The QE period is defined as the final fixation directed to a single location in the visuomotor workspace, within 3° of visual angle, for a minimum of 100ms. The onset of the QE begins at the initiation of the final fixation before the final movement occurs, with an offset when the gaze fixation deviates from the location by 3° of visual angle or more for 100ms (Vickers, 2007). Based on previous research key gaze locations for basketball were defined around the basket and backboard (Vickers, 1996; Wilson, et al., 2009). For netball, key gaze locations were defined as on or just above the net (within 1°), as no backboard is used. A recent meta-analysis (Lebeau et al., 2016) has identified that relative QE duration (fixation duration as a percentage of movement time) has shown larger effect sizes than the absolute measure. Therefore the relative duration measure was adopted in this study. Additionally, a relative measure may help to reduce the large inter-individual variability in QE found in Chapter 2 as well as account for variations in throwing strategy (Lebeau et al., 2016). Movement time was defined as the shot phase (from the first video frame showing upward motion of the ball to the first frame where the ball left the participant's fingertips) described by Vickers (1996), which allowed this to be standardised across both sports.

Performance. The performance measure was based on a scoring system used by Hardy and Parfitt (1991) where 5 was given for a clean basket, 4 for rim and in, 3 for backboard and in (omitted for netball), 2 for rim and out, 1 for backboard and out (omitted for netball) and 0 for a complete miss. This measure was chosen to provide greater precision and sensitivity to performance differences than the simple hit or miss outcome used in Chapter 2.

3.2.4 Procedure

After reading the participant information sheet and signing the consent form, participants were fitted with the ASL eye tracker which was calibrated over 5 points on the basketball hoop or markers on the wall. Participants were given 20 shots to familiarize themselves with the task and with the equipment. Recording checks were performed at the start of every block of shooting, and the eye-tracker re-calibrated where necessary.

Participants performed five blocks of 10 shots, with instructions designed to give varying levels of challenge: a target of 2, 4, 6, 8 or 10 baskets out of 10. The order of the blocks was counterbalanced across participants. If the target was reached in fewer than 10 shots, participants were asked to continue with the remaining shots. After each block of shots participants sat and filled out the Flow Short Scale.

3.2.5 Data Analysis

Gaze and movement data were analysed using Quiet Eye Solutions software (Quiet Eye Solutions Inc.) which allows gaze and motor videos to be time locked and played simultaneously. Quiet eye duration was calculated for all of the 50 shots taken by each participant. Due to tracking issues data from one participant was completely excluded, plus 62 of the remaining 1700 shots (3.65%) across all participants. As there was found to be no difference between basketball and netball in FSS scores, $F(1,30)=0.10$, $p=.76$, $\omega^2=-.029$; QE percentage $F(1,15)=1.67$, $p=.22$, $\omega^2=.038$; or performance, $F(1,32)=.70$, $p=.41$, $\omega^2=-.009$, sports have been combined in the subsequent analyses.

Repeated measures ANOVAs were used to test the effect of goals on flow, QE and performance with a Greenhouse-Geisser correction applied when the assumption of Sphericity was violated. ANOVAs were followed by Bonferroni corrected paired t-tests in all cases. As performance data was not normally distributed, a related samples Friedman's analysis of variance by ranks was conducted. The effect size partial omega squared (ω^2) was calculated for F-tests, Cohen's d for t-tests and Cramer's V for χ^2 tests. Pearson's correlation analyses were used to examine the relationships between flow, performance and quiet eye. To investigate the order of these relationships, mediation analyses were conducted using the PROCESS macro for SPSS (Hayes, 2012), using bootstrapped confidence intervals based on 10,000 samples.

3.3 Results

3.3.1 Experimental Manipulation

To examine the effect of the goals manipulation on flow, a one-way repeated measures ANOVA was conducted on FSS scores, revealing no significant effect, $F(4,132)=1.81$, $p=.13$, $\varepsilon=.68$, $\omega^2=.023$ (Table 3.1).

3.3.2 QE percentage

To test the effect of the goals manipulation on visual attention, a one-way repeated measures ANOVA was conducted on relative QE scores. There was found to be a significant main effect of goals, $F(4,60)=3.47$, $p=.01$, $\omega^2=.132$ (Table 3.1), however, Bonferroni corrected comparisons showed no significant pairwise differences (all *p*s > .05).

3.3.3 Performance

To examine the effect of goals on performance, a related samples Friedman's analysis of variance by ranks was conducted. There was found to be no difference in performance scores, $\chi^2(4)=8.04$, $p=.09$, $V=.479$ (Table 3.1).

Table 3.1: Mean (SD) flow, quiet eye, and performance scores across conditions.

Target	2	4	6	8	10
FSS	3.29 (0.78)	3.01 (0.64)	3.19 (0.89)	3.00 (0.92)	3.18 (0.99)
Performance	3.44 (0.70)	3.42 (0.75)	3.36 (0.80)	3.58 (0.66)	3.44 (0.68)
QE %	60.80 (25.47)	60.90 (25.41)	63.77 (28.04)	76.72 (19.04)	73.28 (19.15)

3.3.4 Relationships

Correlational analyses were conducted to examine the relationship between variables, independent of experimental manipulation. There was found to be a significant correlation between FSS and relative QE, $r(125)=-.20$, $p=.03$; between flow score and performance, $r(174)=-.47$, $p<.001$; but no relationship between relative QE and performance, $r(125)=-.01$, $p=.87$.

A mediation model with QE as the independent variable, performance as the dependent variable and flow score as the mediator was also tested to examine these relationships further. Results indicated that QE was a significant predictor of flow, β=-0.007, p=.03, 95% CI=-0.013 to -0.009 and flow was a significant predictor of performance, β=-0.37, p<.001, 95% CI=-0.53 to -0.22. The total effect model showed no effect of QE on performance, β =-0.0005, p=.87, 95% CI=-0.006 to 0.005), but there was a significant indirect effect of QE on performance via flow, β=0.003, 95% CI=0.0002 to 0.006 (10,000 bootstrapped samples).

3.4 Discussion

This study aimed to investigate the cognitive mechanisms behind the flow state through assessing changes in visual attention during a self-paced sporting task. Based on flow theory (Csikszentmihalyi, 2000), our first hypothesis postulated that moderate goals would facilitate greater flow, however results did not indicate a difference in flow scores across conditions. In comparison to FSS scores obtained from a variety of tasks (Engeser & Rheinberg, 2008), values in this study were only in a mid-range (mean per item=3.12 on a 1-7 scale), indicating the task may not have been sufficiently absorbing. Higher scores on the FSS have been obtained in tasks that allowed a longer period of engagement (Engeser & Rheinberg, 2008). Similarly, previous flow research with basketball (Pates et al., 2002) has utilised three-point shooting which provides a more continuous task, whereas the necessarily stop-start nature of free throws may have prevented flow occurring.

Alternatively, goals given by the experimenter may have been superseded by the general task goal of scoring a basket (e.g., due to goal commitment/acceptance; Locke, Shaw, Saari & Latham, 1981). As a result the given goal may have had limited influence on the perceived challenge-skill balance. Despite the difficulties encountered here, it is our hope that these findings will contribute to successful methodologies in the future. More fruitful approaches may require stronger influences on the perceived challenge-skill balance and more continuous tasks to be suitably absorbing. For instance, given the propensity for flow in video games (Engeser & Rheinberg, 2008), virtual reality sporting environments may provide a highly engaging task, as well as allowing control over task constraints and hence better manipulation of the challenge-skill balance.

A recent perspective on the use of goals suggests that the way in which goals are set may impact whether or not they lead to flow. While goal-setting theory (Locke & Latham, 2013) advocates the use of specific goals to maximise performance, recent work by Swann and colleagues suggests that open goals may be more conducive to flow (Schweickle, Groves, Vella & Swann, 2017). Swann et al., (2017) describe how open goals, which do not specify outcomes, were reported in conjunction with flow states, while specific goals were reported as part of performances interpreted as 'clutch' (Swann et al., 2017). Additionally, Schweickle et al. (2017) found that prescribing participants open goals in a letter/number identification task lead to more flow like experiences, while fixed goals lead to 'clutch' experiences.

Our second hypothesis predicted that increased flow experience would relate to enhanced QE, which was partially supported. As the goals manipulation was unsuccessful, a correlation analysis indicated a significant relationship between the objective measure of visual attention (relative QE) and flow scores. Although the effect was small (r=.20), this is perhaps unsurprising when attempting to relate subjective experience to measurable changes in gaze behavior. Inferring possible causal relationships is difficult given the relational analyses, but mediation may provide initial indications as to causal direction. A small indirect effect of QE on performance through flow score was found. Rather than flow leading to improved attention and subsequently performance, this suggests that optimal QE may have enhanced flow, creating better shooting performance. If this model is supported in future investigations, it may highlight the efficacy of deliberate focusing of visual attention for facilitating flow.

Despite difficulties with experimental manipulations, these results provide initial evidence that visual attention may play an important role in understanding the mechanisms responsible for flow. In particular changes in quiet eye, a behavior associated with top-down attention control (Vine & Wilson, 2011), may indicate that the extreme focus reported during flow (Jackson &

Csikszentmihalyi, 1999) is due to goal-directed influences on attentional selection. Given the findings from mediation, future research may wish to further investigate attentional changes as a possible cause of flow. If this were to be supported, it would highlight the practical efficacy of deliberate focusing strategies for finding flow. Techniques like quiet eye training (Vine & Wilson, 2011) that promote goal-directed control may create an attentional state that is conducive to flow.

A key concern with this research approach relates to finding flow, an elusive experience, in a laboratory setting. Whilst sport research often focuses on more extreme instances, Csikszentmihalyi (2000) discusses the importance of 'micro' flow, which can occur in everyday activities. The type of experience measured in this study is likely to be akin to 'micro' flow, but nonetheless may be representative of attentional changes across all instances of the state. Despite this concern, the ability to manipulate flow in a laboratory setting is an important first step for developing practical applications and addressing mechanisms.

3.4.1 Conclusion

In summary, this study utilised an experimental approach to the flow experience to assess changes in visual attention. Results indicated that the goal manipulation was unsuccessful, but the relationship between flow and relative QE provided tentative evidence for the importance of visual attention during flow. These findings suggest that experimental methodologies and direct measurement techniques may hold promise for better understanding of flow in sport, and should continue to be developed, despite their inherent difficulties (Moller et al., 2010).

3.5 Interim summary

The findings from Chapter 3 provide an initial indication that flow may be related to changes in visual attention, as predicted at the start of the thesis. The relationship observed, however, was only weak, and the experimental manipulation had little effect on flow. In order to develop the experimental method for sport, an overarching aim of the thesis, and to be able to draw firmer conclusions regarding attention, alternative manipulations may be needed. Therefore the following chapter aims to develop an experimental manipulation based on previous success in gaming research, where computer games allowed the demands of the task to be altered to provide an optimal balance of challenge and skill (Keller & Bless, 2008).

4. Chapter 4 – Study 3

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Is flow really effortless? The complex role of effortful attention.

4.1 Introduction

As study 2 (Chapter 3) provided an initial indication that flow may relate to improved attention control, but provided difficulties in the experimental manipulation, the present study aimed to further develop a manipulation of flow in a sport-relevant task. This study again aimed to understand how flow may relate to changes in visual attention, but also addressed the role of attentional effort. While the conceptualization of flow as a decoupling of action from conscious effort and controlled attention (Poldrack et al., 2005) dominates the sport psychology literature (Jackson, 1995; Dietrich, 2006), recent psychophysiological (Peifer et al., 2014) and neuroimaging studies (Ulrich, Keller & Grön, 2016) suggest that this might be an oversimplification of the flow state. As such, the role of attention and effort in the flow experience requires further empirical examination. Therefore the current study seeks to initiate enquiry into the attentional processes underpinning the flow experience in a goal directed, competitive, movement task.

Flow is often described as distinct from other high performance states due to its perceived effortlessness (Bruya, 2010). Whilst high levels of performance can be achieved with increased effort, during flow, performance is reported as automatic, accompanied by confidence and ease (Swann et al., 2012). Qualitative study has likened flow to a state of 'letting it happen', as described by elite golfers who reported a state of optimal performance without deliberative effort (Swann et al., 2016). Dietrich and Stoll (2010, also Dietrich, 2006) suggest that sporting flow relies on a reduction in prefrontal activity, allowing automated action sequences to proceed uninterrupted. It is proposed that hypoactivity of the prefrontal cortex leads to key components of the flow experience like reduced self-awareness, increased fluency and ease of performance, as higher order functions recede (Dietrich & Stoll, 2010).

In contrast to this dominant explanation of flow, findings from outside of sport research have revealed that the flow state is accompanied by increased arousal and mental effort, as indexed by objective, physiological measures (e.g. Peifer et al., 2014). For instance, de Manzano et al. (2010) measured heart rate variability (HRV; the variation in beat-to-beat intervals) while professional pianists played a series of musical pieces and rated their state flow. Reduced HRV has been linked to influence of the sympathetic nervous system and increased mental effort (Berntson et al., 1997), and here was found to be associated with flow (de Manzano et al., 2010). The authors therefore concluded that flow may be a positive state of arousal and high attention.

Additionally, while hypofrontality may be an appealing explanation, neuroimaging studies suggest that flow may instead be characterised by an increase in executive activity; a function dependent on prefrontal activation (Goldman-Rakic, Cools & Srivastava, 1996). For example Yoshida et al. (2014) and Harmat et al. (2015) both failed to find a general reduction in frontal activity in a flow-inducing task. Furthermore, higher-order cognitive mechanisms have been implicated in flow, with fMRI demonstrating increased activity in areas linked to goal-directed behaviour, selective attention and the organization of multi-step behaviours (Ulrich, et al., 2016; Duncan, 2013); functions traditionally associated with effort (Baluch & Itti, 2011; Sarter, Gehring & Kozak, 2006). These neuro-physiological findings conflict with a view of flow as entirely automatic, involving the abdication of control and an absence of attentional processing (Dietrich, 2006).

The characterisation of flow as requiring higher order processes does align with athletes' descriptions of heightened task focus and immunity to distraction during flow (Jackson & Csikszentmihalyi, 1999). This focus is highly suggestive of optimal attentional control; the ability to maintain top down attention to only those stimuli that are relevant to current goals (dorsal network; Corbetta & Shulman, 2002), and resist the distracting influence of stimulus driven attention (ventral network; Corbetta & Shulman, 2002). Efficient top down attentional control is associated with both the planning and control of visually guided actions in general (Land, 2009), and the performance of sport skills under competitive pressure (e.g. Moore et al., 2012; Vine et al., 2013). If this account of flow based on attentional control and higher order processing is valid, those in flow ought to show markers of increased effort (e.g., HRV) and efficient allocation of attention (e.g., gaze behaviour) reflecting goal-directed control. .

The current study seeks to address the question of how effortful attentional processes (Ulrich et al., 2016) and reduced HRV (deManzano et al., 2010) can be reconciled with feelings of effortlessness, through the combination of two theoretical accounts of effort (see Figure 4.1). Firstly, general resource investment (physical or mental) can be predicted through motivational intensity theory (MIT; Wright, 1996; Richter, 2013). Based on the idea that humans will avoid wasting energy, MIT forecasts investment of effort as proportional to task demands until chances of success become low, at which point resources will be withdrawn. MIT therefore predicts little effort in a simple task, a near maximal investment of effort when task demands and personal skills are both high, but a sharp decline when demands become too great. This pattern should be evident in objective physiological markers of effort.

Secondly, the conflict monitoring hypothesis (CMH; Botvinick et al., 2001), outlines how attentional effort is experienced, based on the monitoring of cognitive processes[4]. McGuire and Botvinick (2010) identify that effort arises primarily from unmet demand, which leads to the detection of conflict. This conflict drives the engagement of top-down attention, which is felt as effortful. It is therefore the modulation of top-down processing that is crucial for perceived effort, rather than the activity of top-down processes per se. This key distinction is illustrated by Naccache et al.'s (2005) examination of a patient with a lesion to the anterior cingulate cortex (ACC: a region of medial cortex responsible for conflict detection; Van Veen & Carter, 2002) who was able to maintain executive control, with no felt effort. In combination, MIT and the CMH provide distinct predictions for felt and objective effort, suggesting a dissociation over easy, matched to skill, and hard tasks (see Figure 4.1).

[4] The CMH is not a complete theory of effort, but relates to attentional effort, the focus of this paper.

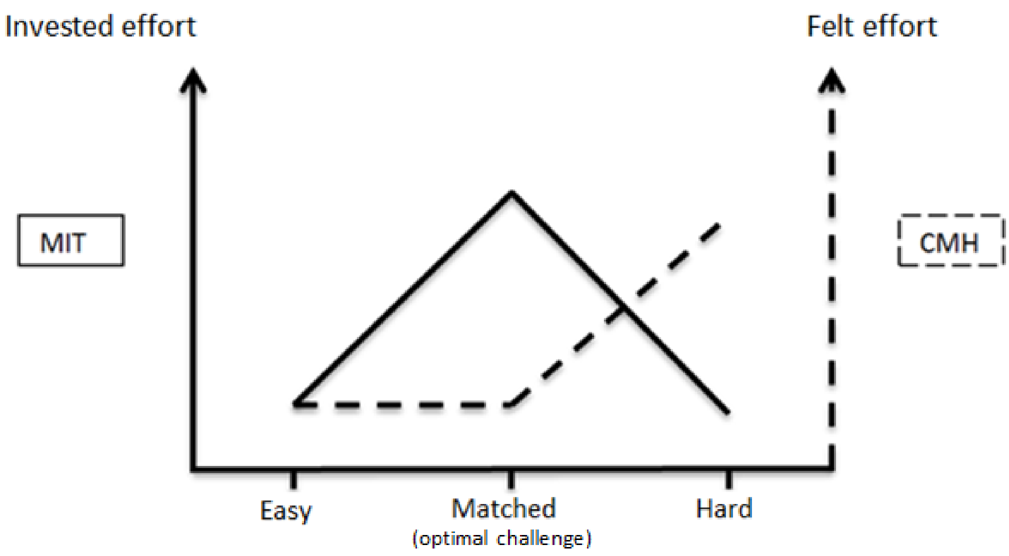


Figure 4.1; A schematic representation of predicted invested (objective) and felt (subjective) effort, based on predictions derived from motivational intensity theory (MIT) and the conflict monitoring hypothesis (CMH) respectively. During an easy task, both felt and invested effort are likely to be low. During an optimally challenging task, there may be a high investment of resources, but limited felt effort, as cognitive control is perfectly meeting demands. During a hard task, felt effort may be high whereas invested effort may be low as resources are withdrawn if there is perceived to be little chance of success.

In order to examine potential changes in effort across varying levels of challenge, this study draws on the experimental approach of research into flow in gaming by controlling task demands. This change of method aims to improve upon the manipulation used in study 2 (Chapter 3). While studies 1b (Chapter 2) and 2 attempted to change the challenge-skill balance through providing goals that altered the *perceived* balance, the use of computer games allows the objective demands of the task to be controlled. For instance, in two experiments Keller et al. (2011) controlled the difficulty of both a computerised quiz and the block stacking game Tetris, providing levels described as 'boredom, fit, and overload'. This reflects quadrants of the flow model reflecting low challenge and high skill, matched challenge and skill and high challenge but low skill respectively. Similarly Tozman et al. (2015) utilised a similar manipulation of three difficulty levels in a driving game. These studies found notable changes in flow experience across the manipulation that allowed them to examine the concurrent psychophysiological changes. Therefore the current study adopts this design in a simulated driving task. The use of the driving task provides an immersive environment where task demands can be controlled, but remains representative of a sporting task, which requires accurate perception and controlled motor responses. As such, this study aimed to further develop the experimental approach of studies 1b (Chapter 2) and 2 (Chapter 3), to examine attentional changes during flow.

To summarise, the current study aimed to extend flow theory development and establish whether the extreme focus reported during flow is related to objective indices of effortful attentional processing. We adopted a design manipulating the challenge-skill balance (see Csikszentmihalyi's, 1990 flow model) to examine effects on (1) attention, (2) effort, and (3) performance. First, we hypothesized that in a 'matched' condition participants would experience the greatest flow (reported task absorption) and demonstrate a peak in objective indices of goal-directed and efficient visual attention. Second, we aimed to test the combined predictions of MIT and the CMH with regards mental effort. Specifically we hypothesized that objective markers of effort will reflect investment of attention, again peaking during the matched condition. However, subjective reports were predicted to dissociate from psychophysiology, showing limited effort during easy and matched conditions but being high in the hard task (see Figure 4.1). We finally hypothesise that performance will be best in the easy condition and worst in the hard condition, with reported fluency of performance exhibiting the same pattern.

4.2 Methods

4.2.1 Participants

An a priori power analysis using G*Power (Faul, Erdfelder, Lang & Buchner, 2007) indicated that based on a medium effect size (Cohen's f = 0.25) for gaze measures found by Cheng (2014), thirty-six participants were required to achieve a power of 0.9 in an F test, given $\alpha = .05$. Thirty-six participants (10 female) who were undergraduate students at the University of Exeter (mean age, 20.21 years; *SD*=1.50) volunteered to take part, and signed informed consent forms. University ethical approval was obtained prior to participant recruitment.

A post-hoc power analysis based on the sample of 36 participants indicated observed power of 1.00, given alpha=0.05 and the observed effect of $\omega^2 = .239$ ($\eta^2 = .266$).

4.2.2 Apparatus

Participants were initially fitted with a Polar heart rate monitoring strap, which records onto a Polar S810i watch (Kempele, Finland). This data was later download into Polar Precision Performance software. Participants sat in a Playseat Alcantra racing chair, fitted with a force-feedback Thrustmaster TX Ferrai 458 (Hillsboro, Oregon) racing wheel, accelerator and brake pedals. Participants played the racing game Forza 5 on the Xbox One (Microsoft), displayed through a Panasonic Viera 50inch HD flat-screen television. The screen was 120cm (approx.) from the participants' eyes. Steering wheel height and distance to the pedals was adjusted for each participant's comfort.

Participants' eye movements were recorded using SMI ETG 2.0 eye tracking glasses (SensoMotoric Instruments, Boston MA) that record onto a customised Samsung Galaxy smartphone. The glasses are lightweight (76g) and record binocular eye movements and the visual scene at 30Hz, to a spatial resolution of 0.5°.

4.2.3 Measures

Flow. State flow was measured using the Flow Short Scale (FSS; Rheinberg, Vollmeyer, & Engeser, 2003, see appendix 5), a questionnaire used frequently in gaming research (e.g. Engeser & Rheinberg, 2008). This scale measures flow through ten questions, loading onto two factors; absorption in the activity, and fluency of performance. Task absorption was used as the primary indicator of the experience of flow (Peifer et al., 2014) whereas fluency was used to index perceived performance. This scale reflects an emphasis on the absorption component of flow (see pages 14 and 48), but has nonetheless been used by many researchers as representative of the flow experience (Engeser & Rheinberg, 2008; Schuler & Brunner, 2009; Tozman et al., 2015). This scale is used here as it reflects core components of the experience; task absorption and fluency of performance. Instructions ask participants '*With regards to the activity you have just completed, to what extent do these statements describe your experience?*' Statements such as '*I feel just the right amount of challenge*' and '*I am totally absorbed in what I am doing* ' relate to absorption. Statements such as '*My thoughts/activities run fluidly and smoothly'* and '*I feel that I have everything under control'* relate to fluency. Questions are rated on a 7-point Likert scale, with responses ranging from '*Very much*' (1) to *'Not at all'* (7), so that low scores indicate greater absorption/fluency. Given the conceptual differences, these subscales were treated independently, and not aggregated.

An initial reliability analysis indicated Cronbach's alpha for scales absorption and fluency to be .66 and .92 respectively. Following a principal components analysis, using a direct oblimin rotation, a slightly altered scale structure was extracted. One item did not load onto either factor sufficiently strongly (loadings < .4) and one exhibited similar loading for both. As a result these 2 items were excluded. As subsequent reliability analyses indicated Cronbach's alpha was improved for absorption (.75)[5] and maintained for fluency (.91), the modified factorial structure was retained.

Top down attention: Gaze variability. Barret, Tugade and Engle (2004) suggest the best way to determine how attention is being controlled is to determine what goal-directed control would resemble in the given situation. The variability of gaze behaviour has previously been used to indicate inefficiency of attention, with a high degree of variation indicating gaze is not efficiently allocated to the most relevant information (Janelle, 2002). For example, in a simulated racing task Wilson and colleagues found that the standard deviation of horizontal eye movements increased (became more variable) when participants were anxious, leading to impaired driving performance (Wilson et al., 2006). As such gaze variability was used here as a measure of the focused, top-down attention predicted to occur during absorption and flow. Horizontal eye position data was captured during the second lap of each race and downloaded via BeGaze 3.5 software to an Excel spreadsheet, where a standard deviation was computed to assess efficiency of visual attention control (as Wilson, et al., 2006).

Subjective mental effort. Subjective mental effort was indexed using the Rating Scale of Mental Effort (RSME, Zijlstra, 1993, see appendix 6). The RSME is a unidimensional visual analogue scale, ranging from 0 to 150, with descriptors

[5] Excluded items were item 3, 'I do not notice time passing', which did not load strongly onto either scale, and item 5, 'My mind is completely clear', which loaded weakly on both. Although the reliability value for the absorption subscale is still fairly low, suggesting that it is not fully unidimensional, it is retained as previous research has also found low alpha values for this subscale (e.g., Engeser & Rheinberg, 2008).

along the scale, such as 'Absolutely no effort', 'Considerable effort' and 'Extreme effort'. The RSME has been widely used in driving research (e.g., Wilson, et al., 2006) and has been found to be reliable over repeated administrations in laboratory (r = 0.88) and work settings (r = 0.78; Zijlstra, 1993). The scale has also been found to correlate with spectral changes in HRV (Zijlstra, 1993).

Objective mental effort. Objective mental effort was indexed through cardiac measures, principally heart rate variability (HRV), as in recent flow studies (Tozman et al., 2015; Peifer et al., 2014). HRV is the variation in the interval between two successive heart beats (Berntson et al., 1997), and can be assessed in low frequency (sometimes termed mid-frequency, 0.04-0.15Hz) and high frequency bands (0.15-0.4Hz), both of which have been used to index mental effort (DeRivecourt et al., 2008). The variation in beat-to-beat interval is a result of control by the cardiac sinoatrial node, which is innervated by sympathetic and parasympathetic branches of the autonomic nervous system. Variability in the high frequency band is predominantly influenced by the vagus nerve (parasympathetic), whilst the low frequency band reflects influence of both sympathetic and parasympathetic branches. A robust finding is that more complex, effortful cognitive tasks reduce HRV due to increased arousal and activation of the sympathetic nervous system, creating a more regular heartbeat (Cacioppo, Tassinary & Berntson, 2007).

Recording epochs were standardized based on the recommendations of the Task Force of the European Society of Cardiology (1996). It is also recommended that for reliable recording a time period should be used that allows at least ten samples of the target rhythm, corresponding to 1 minute for HF and 2 minutes for LF (Berntson et al., 1997). Raw heart rate was recorded through the Polar heart rate strap and converted to inter-beat intervals (IBI) using Kubios HRV Analysis Software (Biomedical Signal Analysis Group, University of Kuopio, Finland; Niskanen et al., 2004). IBIs were converted into separate frequency domain power components; low-frequency HRV (0.04-0.15Hz) and high-frequency HRV (0.14-0.4Hz), presented in ms^2. Raw heart rate data were also recorded as a more general measure of arousal and engagement (Cacioppo, et al., 2007).

The raw HR inter-beat-interval (IBI) data was filtered using the Polar Precision Performance SW analysis software algorithm, set at moderate filtering level. The algorithm uses median and moving average based filtering methods to substitute detected errors and missing beats (0.2% of total) with corrected values (set at moderate filtering power and 6bpm protection zone). Recordings were also screened manually for erroneous data, which were removed as necessary (10% of total). The smoothed data were analyzed with Kubios HRV Analysis Software. The last 1.45min was selected for analysis[6] and a moderate artefact removal applied. The software provides information in both the time and frequency domains. Mean heart rate was recorded from the time domain and HF and LF ms^2 power from the frequency domain.

Performance. Performance was measured by average speed (mph) taken from the second lap of each 2-lap race. The second lap was used because it approximately corresponded to the HRV epoch; it allowed participants to become immersed in the race; and self-report measures were more likely to reflect the experience of the second lap due to a recency effect. The lap times were recorded from the eye tracking video after the testing session and converted to average speed (lap distance / time taken).

4.2.4 Procedure

Participants attended testing on one occasion, for approximately one hour and forty minutes. Participants first read the information sheet and had the experiment explained verbally before signing the consent form. The Polar heart rate strap was then fitted, with electrodes wetted to reduce impedance. Participants sat in the racing chair, with the pedals adjusted for comfort. Participants put on the SMI eye tracking glasses, which were calibrated over three points, and the tracking was checked over a variety of markers across the screen.

Participants were required to complete thirteen races, each of two laps. Instructions were given to ‘complete the race as quickly as you can, but try to

[6] On the ‘easy’ driving level 13 of the 36 participants completed the race in less than 2 minutes. In order to include these trials, a standard time of 1 minute 45 seconds was used. As 2 minute recordings showed a correlation of r=.98 with the 1.45 times, it is unlikely that this influenced the reliability of the LF outputs.

avoid crashing'. Following every race participants were told their time and encouraged to beat it on the following trial. The training phase consisted of ten races on the same track; chosen to be of moderate difficulty with smooth corners. Pilot testing suggested that performance would become proficient but that participants would not reach a ceiling in performance after ten laps. A training phase was necessary as a level of skill is suggested to be beneficial in finding flow (Csikszentmihalyi, 1990). Following each of the ten races participants completed the FSS and RSME and were given the opportunity to take a break before the test phase. At this point the heart rate strap electrodes were re-wetted and the eye tracker was recalibrated.

The test phase involved racing on three different racetracks; one chosen to be very easy, one very difficult, and one matched to skills. This approach reflects Csikszentmihalyi's (1990) flow model and is identified by Moller et al. (2010) as the standard protocol in gaming studies. The 'easy' track was based on a speedway where the course was a simple circle, providing little challenge. The 'hard' track involved a lot of sharp corners and was very challenging to navigate at speed. The 'matched' track was a repeat of the practised race from the training phase. The order of the 'easy' and 'hard' levels was randomised across participants, but the 'matched' level was always done last to keep it distinct from the training phase. Having just completed 10 races, the novel tracks were driven first to avoid participants being bored/tired of the matched track, which would be detrimental to flow. The car and racing settings were standardised across all races and participants. After each race participants completed the FSS and RSME instruments.

4.2.5 Data Analysis

Paired t-tests were used to test performance and flow from the first to the tenth race of the training phase to establish improvement. One-way repeated measures MANOVA and ANOVA were used to assess differences in dependent variables across test-phase conditions. Where data were not normally distributed transformations were applied, and a Greenhouse-Geisser correction was used when the assumption of Sphericity was violated. Significant ANOVAs were followed by Bonferroni corrected paired t-tests in all cases. The effect size partial omega squared (ω^2) was calculated for F-tests and Cohen's *d* for all t-tests.

4.3 Results

4.3.1 Training Phase

To check for improved performance over the training phase, paired t-tests were conducted, revealing a significant increase in average speed (mph) from race 1 (M = 92.20± 14.65) to race 10 (M = 110.35±11.35), $t(32)=6.25$, $p<.001$, $d=1.379$. Similarly, a paired t-test also indicated increased fluency (FSS) from race 1 (M=22.28±7.85) to race 10 (M=14.56±6.35), $t(31)=4.79$, $p<.001$, $d=1.077$. To check for an increase in flow over the training phase, a paired t-test was conducted on FSS absorption scores, revealing a significant increase in absorption from race 1 (M=12.78±3.41) to race 10 (M=10.28±4.71), $t(31)=3.34$, $p=.002$, $d=.594$.[7]

4.3.2 Self-Reported Absorption (FSS)

ANOVA was conducted to assess the effect of experimental condition (easy/matched/hard) on perceived absorption, revealing a significant main effect of condition, $F(2,70)=9.58$, $p<.001$, $\omega^2=.192$. Participants were most absorbed in the Matched condition with pairwise differences between Matched (M=9.00±4.26) and Easy (M=11.97±4.78), $p<.001$, $d=.671$; and between Matched and Hard (M=11.50±4.93), $p=.002$, $d=.579$. There was no difference between Easy and Hard, $p=1.00$, $d=.100$ (Figure 4.2).

4.3.3 Self-Reported Fluency (FSS)

ANOVA was also conducted to assess the effect of condition on perceived fluency, revealing a significant main effect, $F(2,70)=63.54$, $p<.001$, $\omega^2=.631$. Fluency decreased from Easy to Matched to Hard, with significant pairwise differences between Easy (M=7.11±3.21) and Hard (M=16.83±5.84), $p<.001$,

[7] It is worth noting that during the matched condition participants performed significantly better ($t(31)=2.03$ $p=.05$, $d=.330$) and reported significantly more absorption ($t(31)=2.01$ $p=.05$, $d=.178$) and fluency ($t(31)=3.59$, $p=.001$, $d=.332$) than during the last training race.

d=1.991; and between Matched (M=8.08±3.19) and Hard, p<.001, d=1.720; but not Easy and Matched, p=.19, d=.346 (Figure 4.2)[8].

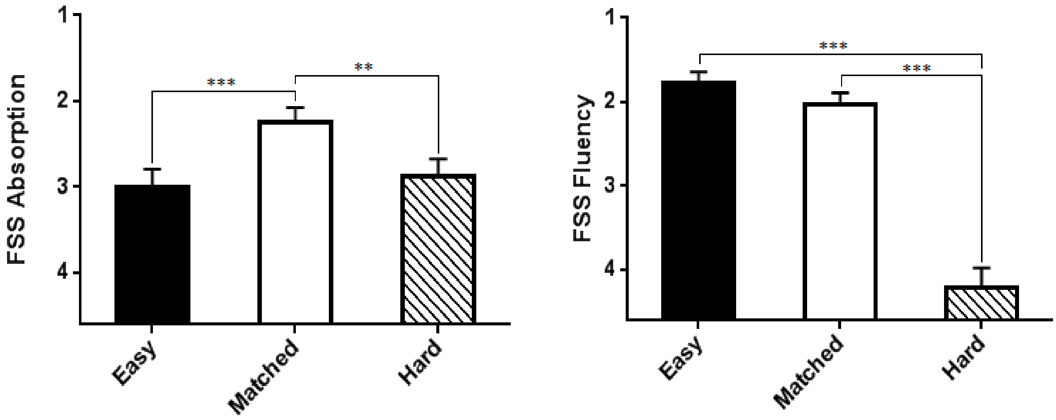


Figure 4.2. Mean (standard error) per item scores for FSS scales absorption and fluency (p<.01, ***p<.001).**

4.3.4 Attention (Gaze) Control

To assess the effect of condition on top down visual attention, ANOVA was conducted on gaze variability data, revealing a significant effect, $F(2,62)=11.26$, $p<.001$, $\omega^2=.239$. Participants showed lowest gaze variability in the matched condition with significant pairwise differences were between Easy (M=11.33±4.71) and Hard (M=132.37±34.35), p=.05, d=.375, and Matched and Hard, p<.001, d=.820 but not Easy and Matched (M=99.61±43.08), p=.31 d=.253 (Figure 4.3).

[8] The original scale structure of the FSS gave almost identical results for fluency, but pairwise comparisons for absorption showed reduced significance; $F(2,70)=6.35$, $p=.003$, $\omega^2=.128$; Easy (M=12.14±4.36) and Matched (M=9.44±4.24), p=.003, d=.627; Matched and Hard (M=11.33±4.71), p=.06, d=.421; Easy and Hard, p=.97, d=.177.

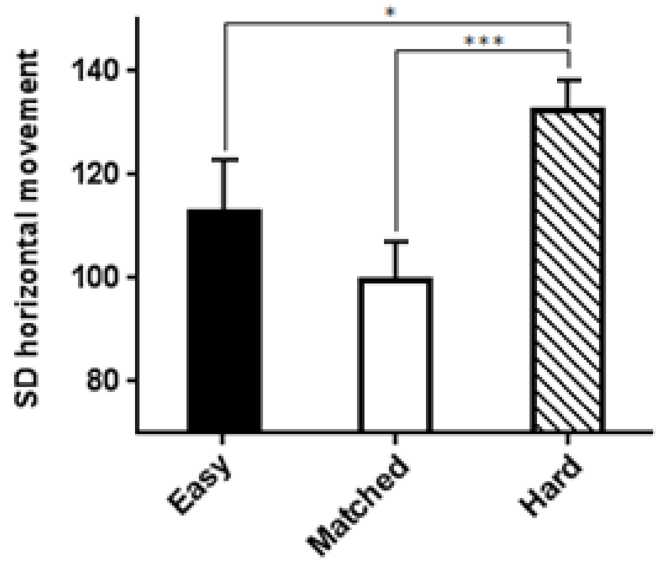


Figure 4.3; Mean standard deviation (standard error) of horizontal eye movements (gaze variability) (*p<.05, ***p<.001).

4.3.5 Self-Reported Mental Effort (RSME)

There were a small number of missing RSME scores (8 cases, .02% overall) due to participants omitting to register a response. These were imputed using an expectation maximization algorithm as Little's Missing Completely at Random test indicated these cases to be random (χ^2 (44)=52.88, *p*=.169). In assessing the effect of condition on perceived effort, ANOVA indicated a significant effect, $F(2,70)=48.92$, $p<.001$, $\varepsilon=.80$, $\omega^2=.567$. Participants reported increasing effort from Easy to Matched to Hard, with significant pairwise differences existing between Easy (M=53.03 ±30.16) and Matched (M=77.57 ±26.26), $p<.001$, $d=.850$; Matched and Hard (M=91.11 ±25.36) $p=.006$, $d=.524$; and Easy and Hard conditions, $p<.001$, $d=1.356$ (Figure 4.4a).

4.3.6 Objective Mental Effort (Heart Rate / HRV)

To assess the general effect of condition on physiological markers of effort, a repeated-measures MANOVA was run on raw heart rate, low frequency and high frequency variability data (all log transformed). There was found to be a significant effect of condition, Wilks' $\Lambda=.49$, $F(6,18)=3.10$, $p=.02$.

Follow up ANOVA on low frequency HRV revealed a significant effect of condition $F(2,48)=3.66$, $p=.03$, $\omega^2=.094$. Low frequency variability indicated a U-shaped function with the matched condition displaying the least variability, although there were no significant pairwise differences between Easy (M=1069.19±841.79) and Hard (M=1082.57±1113.37), p=1.00, d=-.002, Easy and Matched (M=846.90±809.34), p=.06, d=.407 or Hard and Matched, p=.15 d=.412 conditions (see Figure 4.4b).

High frequency variability also demonstrated a significant effect of condition, $F(2,48)=14.20$, $p<.001$, ε=.76, ω^2=.339, showing a clear U-shaped relationship, with significant differences between Easy (M=735.33±919.16) and Matched (M=354.24±432.32) p=.001, d=.799, and between Hard (M=596.02±618.69) and Matched, p=.003, d=.842. There was no difference between Easy and Hard conditions, p=.10, d=.073 (Figure 4.4b).

Raw heart rate also indicated a U-shaped relationship, this time inverted, as ANOVA showed a significant effect of time, $F(2,46)=14.09$, $p<.001$, ε=.64, ω^2=.347, with pairwise differences between Easy (M=73.06±16.36) and Matched (M=80.81±12.06), p=.002, d=.755 and Hard (M=74.98±10.07) and Matched, p=.002, d=.770. There was no difference in HR between Easy and Hard levels, p=1.00, d=-.052 (see Figure 4.4b).

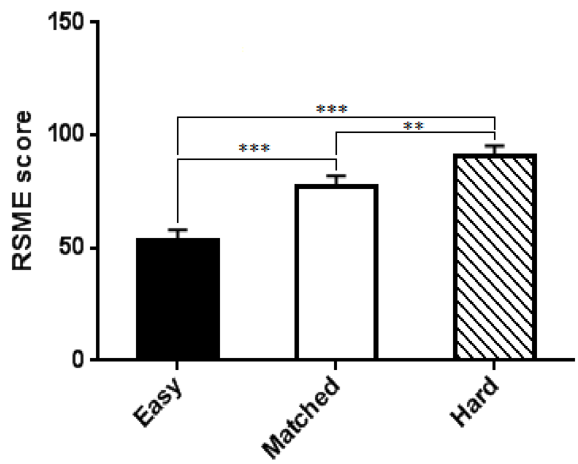


Figure 4.4 a). Mean (standard error) self-reported effort scores (RSME) (p<.01, ***p<.001).**

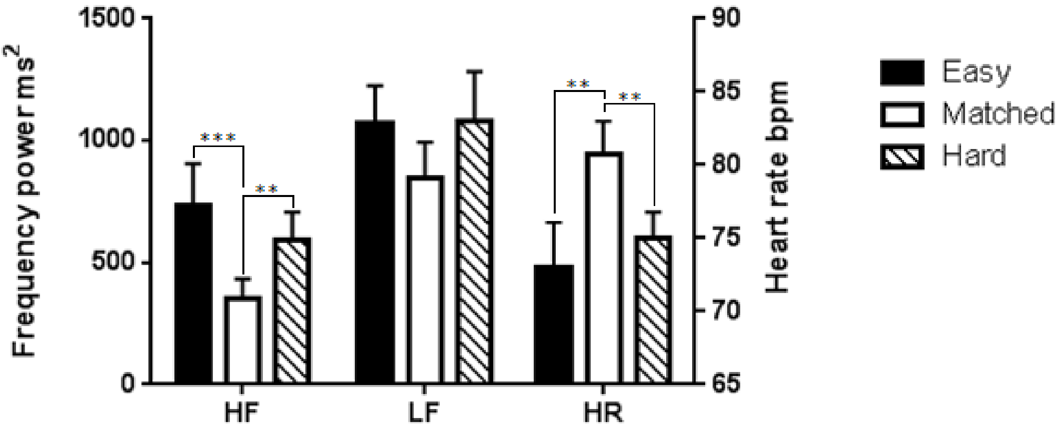


Figure 4.4 b). Mean (standard error) heart rate variability (left-hand scale) and heart rate (right-hand scale) across experimental conditions. HF = high frequency band; LF = low frequency band; HR = heart rate (p<.01, ***p<.001).**

4.3.7 Performance

To check the manipulation of race difficulty, ANOVA of average speed showed a significant effect of condition, $F(2,64)=529.60$, $p<.001$, $\varepsilon=.77$, $\omega^2=.940$, with performance improving from easy to Matched to Hard. Significant pairwise differences were found between Easy ($M=160.59\pm15.72$) and Matched ($M=113.68\pm9.82$), $p<.001$, $d=3.534$, Matched and Hard ($M=72.60\pm10.80$), $p<.001$, $d=3.976$ and Easy and Hard conditions, $p<.001$, $d=6.504$.

4.4 Discussion

This study aimed to test theoretically driven hypotheses related to the issue of attentional effort during flow through direct measurement techniques in a simulated sporting task. Specifically, we explored how combined predictions of MIT (Wright, 1996) and the CMH (Botvinick et al., 2001) may explain a dissociation in felt and objective attentional effort. While descriptions of flow allude to the role of attention, this study provides the first attempt to take objective measurements of generalized mental effort alongside task-specific attentional control. Our aim was to challenge the dominant view that flow in sport can be explained without recourse to effortful attention control (Jackson, 1995; Swann et al., 2016; Dietrich & Stoll, 2010).

Results suggested that the driving task induced flow, with the experimental manipulation successfully creating significant differences in absorption between conditions (Figure 4.2). The mean FSS item scores in the matched condition (2.1 per item on 1-7 Likert scale) are identical to the peak scores obtained by Engeser and Rheinberg (2008) in a gaming task, supporting the induction of flow. As such, this was an effective change in method from Chapter 3, where there was little effect of the manipulation. As hypothesized, there were differences in the way that participants responded to both subscales. Participants scored highly on the fluency scale during the easy and matched, but not in the hard condition, which reflected the pattern of performance. Fluency indicates smoothness of performance, and hence cannot distinguish between an easy task and a task in which flow is achieved. However, absorption, which is more representative of the immersive experience of flow (Peifer et al., 2014), revealed an inverted-U relationship, with highest scores during the matched level. While it may not be possible to suggest that all participants in the matched condition experienced flow, the absorption scores suggest that the matched condition created the greatest flow experience.

Our first hypothesis reflected our postulation that flow, as a state of focused attention, would be characterized by more efficient visual attentional control; indexed by lower variability of gaze. We found that the standard deviation of horizontal gaze position was significantly lower in the matched condition compared to the hard condition (see Figure 4.3). The U-shaped trend was as hypothesised, although the difference in gaze variability between easy and matched conditions was non-significant, with a small effect size. The gaze pattern follows a similar trend to the reports of absorption, suggesting that self-reported focus during the matched condition was also manifested in more focused gaze. As the expected pattern was observed but some differences were small, we partially supported our first hypothesis that a matched challenge-skill condition leads to absorption and efficient goal-directed visual attention.

Our second hypothesis was related to the integrated predictions of MIT and the CMH (see Figure 4.1). Based on MIT (Wright, 1996), objective mental effort was predicted to peak during the matched condition as resource mobilisation is proportional to task difficulty, until perceived chances of success become low, whereupon resources are withdrawn. Participants' HRV data revealed this predicted U-shaped trend, although pairwise differences were only significant in the high frequency data: significantly lower variability in the matched condition reflecting an increased engagement of attentional effort (Figure 4.4b). While previous research has found increased variability to correlate with flow *within a condition* (Peifer et al., 2014), research by Keller, Bless, Blomann and Kleinböhl (2011) and Tozman et al. (2015) utilizing similar manipulations to the present study, have found a reduction in HRV in matched to skills conditions. The observed pattern parallels peak ratings of absorption, peak heart rate and reduced gaze variability in the matched condition, suggesting that the experience of flow-like absorption is based on an efficient, but effortful, engagement of attention.

Based on the CMH (Botvinick et al., 2001) little felt effort was predicted during easy and matched conditions, as no change in cognitive control was necessary, but high reported effort was expected in the hard condition. As a linear pattern was found in RSME scores (Figure 4.4a) this prediction is largely supported; the matched condition produced felt effort at a mid-point between easy and hard conditions. This finding does support the dissociation between felt and observed effort illustrated in Figure 4.1, as even though the matched condition created the most objective effort, it was not experienced as the most effortful. Overall findings closely paralleled the model, hence combined predictions of the CMH and MIT may make a useful contribution to our understanding of flow.

Our final hypothesis was also supported, with the expected decrease in performance and reported fluency as task demands increased. While correlational research has traditionally equated flow with performance (Jackson, Thomas Marsh & Smethurst, 2001), the experimental approach used here suggests flow is dependent on optimal challenge and task absorption more than performance. If flow was merely a 'glow effect' of performing well, highest scores would have been seen in the easy condition. Overall, the results of this study reveal some promising findings that help to disentangle the felt experience of flow from the likely attentional mechanisms. The fluency measure seems to reflect the ease of the task; as revealed by similar profiles for performance, fluency and self-reported effort (though inverted). As such fluency is related to the feeling of automaticity that Dietrich's transient hypofrontality theory predicts. However, absorption reflects immersion in the task; focused and goal-directed attention that is resistant to distractibility, through mechanisms related to effort that are unavailable to introspection. The interesting dichotomy here is that flow appears to reflect a state that is both effortful and efficient; allowing automated sequences to take care of themselves, so that *more* attention can be paid to essential aspects of the activity (Csikszentmihalyi & Nakamura, 2010).

The results from this novel study highlight the efficacy of applying experimental methods to sport research when seeking to investigate causal mechanisms underpinning the flow-performance relationship. However, applied psychologists seeking to explore methods for increasing the likelihood that a performer might experience flow during competition should draw conclusions with caution. First, the driving task chosen provides both strengths and weaknesses in this study. Although the task was a simulation, it provided many aspects of a sporting performance, requiring concentration, accurate perception and coordination of motor responses. While a key element of sport, physical exertion is absent, this was a conscious decision given the need to isolate changes in physiological indicators of mental effort, without contamination from bodily movement. However, future research may wish to examine more active tasks within a similar paradigm.

Second, the order of experimental conditions, where the matched level was done last, also provided the potential for fatigue or boredom to influence the findings. This decision was made so that the matched condition race was distinct from the preceding training phase (using the same track) and the FSS results suggest that boredom was not a factor. However, future studies could use full randomization to avoid any potentially confounding order effects. Third, whilst used widely to index mental effort, HRV is an indirect measure which also responds to more general stress and arousal processes (Berntson, et al., 1997). Future research should therefore include subjective measures of stress and anxiety, especially as these are also predicted to influence mental effort (Wilson, 2008). An additional concern may be the use of a flow scale that emphasizes task absorption, and does not include items relating to the positive nature of the flow experience. This scale was used to reflect this conceptualization of flow, emphasizing the absorption component. This scale has been widely used in gaming research (Engeser & Rheinberg, 2008; Tozman et al., 2015) to indicate flow occurrence (which is unlikely to be a negative experience during a computer game) and we wished to align the findings with this body of research. Finally, practicing on the race track that was subsequently used as the matched race may have provided a potential confound, as familiarity with the track could have influenced eye movements. For example, Greene and Rayner (2001) showed that familiarity with distractors facilitated visual search through making longer, but fewer fixations. This effect could potentially account for gaze changes found here.

4.4.1 Conclusion

While flow presents challenges for experimental research (Moller et al., 2010), these results suggest that during a matched to skills task participants were more absorbed, invested more attentional effort and directed their gaze more efficiently. In addition, our findings largely supported the divergent predictions of MIT and the CMH for subjective and objective effort during an optimally challenging task. In contrast to traditional views, a state of flow may require effortful attention control even if it feels effortless. From an applied perspective, traditional effortful focusing strategies may therefore be beneficial for initiating flow across training and competitive settings.

4.5 Interim summary

This study (3) aimed to develop the experimental approach to flow, following difficulties in manipulation in study 2 (Chapter 3). Additionally, the gaze findings here provide support for the tentative flow-QE relationship identified in Chapter 3, together indicating that flow may be related to more focused visual attention. It remains to be established, however, whether attention changes create the experience of flow or are a result of it. Therefore study 4 (Chapter 5) aims to use an attentional manipulation, instead of controlling the challenge-skill balance, to test the causal effect of attention on flow. An attentional focus manipulation was chosen, firstly, based on the weight of evidence for the beneficial effects of focusing externally (Wulf, 2013), and secondly as priming an external focus of attention promotes good attention control through directing attention towards relevant task information and away from irrelevant self-referential processing

(Wulf, 2013). If this experimental manipulation is effective, it may also highlight potential applications for flow interventions. Following the protocol of study 3 (Chapter 4), similar measures of objective and subjective effort will be taken to assess whether changes in flow, as a result of the manipulation, are related to changes in felt and observed effort. Additionally, the 'matched' level from study 3 will be used in study 4 to provide a task that is optimally challenging, and to allow comparison between results.

The results of study 3 (Chapter 4) have also highlighted that during an optimally challenging task, attention is focused, mental effort is invested and a state of absorption can occur. Study 4 (Chapter 5) will seek to further examine the psychological state that arises from an optimally challenging task, and how that may contribute to a state of focused performance; in particular pertaining to the role of enhanced outcome expectancies, such as self-efficacy. Athletes identify that confidence is an important antecedent of flow experience (Swann et al., 2012; Koehn, 2013), and as high self-efficacy has been linked to cognitive effort and attention control (Themanson et al., 2008), it may further enhance the state of focus seen during flow. Understanding additional psychological factors that contribute to flow may also contribute to producing effective interventions.

5. Chapter 5 – Study 4

The effect of attentional focus on flow experience

5.1 Introduction

Achieving the optimal mental state for peak performance is a major goal for all athletes. To demonstrate the skills developed through training, unencumbered by distracting or disruptive thoughts, athletes must find a facilitative level of arousal and focus their attention efficiently towards key elements of the task (Memmert, 2009; Eysenck & Wilson, 2016). During the state of flow, or 'the zone', athletes report an intense task focus and complete absorption occurring with ease (Jackson & Csikszentmihalyi, 1999, Dietrich & Stoll, 2010). A greater understanding of the cognitive mechanisms responsible for flow will enable people in sporting, work and leisure activities to achieve flow-like states more often, obtaining the associated motivation and performance benefits (Csikszentmihalyi, 2000; Jackson et al., 2001). Given the central role of attention in flow (Csikszentmihalyi, 1996; Ullén et al., 2010), this study aimed to investigate the effect of attentional focus on flow. Additionally we aimed to further investigate how the psychological state of flow contributes to performance, through the potential contributory role of self-efficacy.

Flow has long been described in attentional terms, but researchers have only recently begun to examine the specific processes responsible. Additionally, research to date has however focused on changes *associated* with flow rather than *causally* responsible (Swann, Crust & Vella, 2017), limiting the ability to identify attention as a true mechanism. Therefore experimental approaches that control attention are needed to develop flow theory as well as practical applications. A fitting attentional manipulation may be to promote an external focus of attention. Focusing externally (on the movement effect), relative to internally (on bodily movements), has been found to provide substantial benefits for motor learning and performance (Wulf, Höß & Prinz, 1998; Wulf, McNevin & Shea, 2001; Wulf, 2013; Bertollo et al., 2015). The principal mechanism for the benefits of an external focus seems to be through enhanced motor automaticity (Kal, van der Kamp, & Houdijk, 2013; Lohse et al., 2012; Wulf, McNevin, & Shea, 2001). For instance Kal, van der Kamp and Houdijk (2013) found reduced dual-task costs in a leg flexion task, and Wulf et al. (2001) found reduced probe reaction times in a balance task as a result of an external focus, indicating movements were not being executed through controlled processing. Similarly, McNevin, Shea and Wulf (2003) found more high frequency movement adjustments in a stabilometer task, suggesting that an external focus allowed performers to make use of self-organising capabilities of the motor system. As such, an external focus not only increases movement accuracy but also movement efficiency (Wulf, 2013). This type of smooth and efficient motor control is typical of athletes' descriptions of flow (Jackson & Csikszentmihalyi, 1999; Swann et al., 2015).

Additionally an external focus avoids the disruptive effects of self-focus on the monitoring and control of movement mechanics (Beilock & Carr, 2001; Masters & Maxwell, 2008). Wulf and colleagues describe this through the 'constrained action hypothesis' (McNevin, Shea, & Wulf 2003; Wulf, McNevin, & Shea 2001); individuals who attempt to consciously control their movements may constraint their motor system, disrupting self-organising processes. Notably, Wulf and Lewthwaite (2010) link the self-schema system, activated through an internal focus, to the functional network of cortical mid-line structures which have been found to be inactive during flow (Ulrich et al., 2014; Ulrich et al., 2016). An external focus of attention may therefore further contribute to finding flow, through facilitating the reduction in self-consciousness seen in flow states.

There may also be an important overlap between the attentional focus and flow literatures, in terms of outcome expectancies. Within the OPTIMAL motor learning theory, Wulf and Lewthwaite (2016) outline how a range of predictive cognitions regarding future outcomes, referred to as outcome expectancies, may contribute to motor learning and motor performance. Enhanced expectancies refer to positive beliefs about future outcomes including concepts such as self-efficacy, self-confidence and perceived competence. Enhanced expectancies are suggested to benefit movement through goal-action coupling - maintaining a focus on the task goal and away from the self. An external focus of attention similarly contributes to goal-action coupling, and hence performance, with better movement outcomes leading to enhanced self-efficacy expectations in a feedback loop.

Within the sporting literature, enhanced expectancies, in particular self-confidence, have been associated with both flow (Schuler & Nakamura, 2013; Stavrou & Zervas, 2004; Swann et al., 2012; Koehn, 2013) and performance (Locke et al., 1984; Bouffard-Bouchard, 1990; McMay, Lewthwaite & Wulf, 2012). There are notable similarities between flow and enhanced expectancies in terms of the relationship with the challenge-skill balance (Kawabata & Mallett, 2011) and beneficial effects for focused attention (Bandura, 1993; Themanson & Rosen, 2015). Bandura (1993) identifies that individuals with high self-efficacy approach difficult tasks as a challenge and invest greater effort in them. Equally, Bandura describes *mastery experiences,* which occur when individuals experience success in challenging tasks, as the most effective way of developing self-efficacy. As such, self-efficacy may both enhance the way a challenge is approached, and be augmented by the challenge (Salanova, Bakker & Llorens, 2006). Therefore, we would expect enhanced expectancies during situations of optimal challenge, and a positive relationship between flow and outcome expectancies.

In summary, previous studies (Chapters 3 and 4) have indicated an association between improved attention and flow, but research is yet to establish a causal direction. Therefore this study primarily aimed to assess the effect of instructions designed to create an internal versus external focus of attention on flow and performance. Additionally, to further understand psychological processes that may contribute to the state of focused attention during flow, self-efficacy was assessed in relation to flow and markers of attention control. To this end, participants were given attentional focus instructions before completing the simulated driving task used in Chapter 4. It was predicted, based on a range of previous work (Lohse, Jones, Healy & Sherwood, 2014; McNevin, Shea & Wulf, 2003), that an external focus would promote improved performance, motor control and attention, and as a result, greater flow experience. Further, self-focus (on the hands during driving) has been shown to have negative performance consequences (Wilson et al., 2007). Additionally it was predicted that self-efficacy would further contribute to a state of flow, through a relationship with markers of attention control and performance.

5.2 Methods

5.2.1Participants

Based on an a priori power analysis using G*Power (Faul, Erdfelder, Lang & Buchner, 2007), 33 participants were required in order to find a medium effect (*d*=0.6, based on mean of pairwise comparisons in Chapter 4) in the FSS questionnaire, with a power of .90. To this end, 33 participants (16 female, mean age=22.6 *SD*=3.4) were recruited from undergraduate and postgraduate students. A post-hoc power analysis based on the sample of 33 participants indicated observed power of 1.00, given alpha=0.05 and the observed effect of *d*=1.78. Institutional ethical approval was acquired prior to recruitment, and participants gave written informed consent at the start of testing.

5.2.2 Apparatus

The simulated race used the game Forza 5 on the Xbox One (Microsoft), displayed through a Panasonic Viera 50inch HD flat-screen television. Participants sat in a Playseat Alcantra racing chair, fitted with a force-feedback Thrustmaster TX Ferrai 458 (Hillsboro, Oregon) racing wheel, accelerator and brake pedals. The screen was 120cm (approx.) from the participants' eyes. Steering wheel height and distance to the pedals was adjusted for each participant. A potentiometer, recording wheel movements in degrees of deviation from the 12 o'clock position at 60Hz, was attached to the steering wheel column. The wheel recorded onto a Dell Inspiron Laptop positioned behind the participants' seat.

Participants' eye movements were recorded using SMI ETG 2.0 eye tracking glasses (SensoMotoric Instruments, Boston MA) that record onto a customised Samsung Galaxy smartphone. The glasses are lightweight (76g) and record binocular eye movements to a spatial resolution of 0.5° at a rate of 60Hz, allowing synchronisation with the steering wheel potentiometer. Participants had their head stabilised in a customised chin rest to eliminate head movement.

5.2.3 Measures

5.2.3.1 Manipulation check. To check for adherence to instructions participants indicated on a 1-10 scale the extent to which they were able to maintain the instructed focus, from '*1-Not at all*' to *'10-Completely'* (Wells & Papageorgiou, 1998).

5.2.3.2 Flow. State flow was measured using questions from the Flow Short Scale (FSS; Rheinberg, Vollmeyer, & Engeser, 2003, see appendix 5), a questionnaire used frequently in gaming research (e.g. Engeser & Rheinberg, 2008). 10 items such as '*I feel just the right amount of challenge*', '*I have no difficulty concentrating'* and '*I am totally absorbed in what I am doing*' are rated for agreement on a 7-point Likert scale, with responses ranging from '*Very much'* to *'Not at all'.* Low scores on this scale represent higher felt flow, but for ease of interpretation and analysis, scores were inverted when collating questionnaire data, such that higher values indicate higher flow.

5.2.3.3 Felt effort. The Rating Scale of Mental Effort (RSME, Zijlstra, 1993, see appendix 6) visual analogue scale was used as an index of subjective mental effort, as in Chapter 4. The RSME ranges from 0 to 150, with descriptors along the scale, such as 'Absolutely no effort', 'Considerable effort' and 'Extreme effort'. The RSME has been widely used in driving research (e.g., Wilson, et al., 2006; Chapter 4) and has been found to be reliable over repeated administrations in laboratory (r = 0.88) and work settings (r = 0.78; Zijlstra, 1993), and relates to spectral changes in HRV (Zijlstra, 1993).

5.2.3.4 Enhanced expectancies. As in Badami, VaezMousavi, Wulf and Namazizadeh (2011) enhanced expectancies were assessed using the perceived competence subscale of the intrinsic motivation inventory (IMI; McAuley, Duncan & Tammen, 1989). The items *'I think I am pretty good at this activity', 'I think I did pretty well at this activity compared to other students*' and '*This was an activity that I couldn't do very well*' (R) are rated on a 1-7 scale. These items gave Cronbach's alpha=.84.

5.2.3.5 Objective effort*.* As previously, objective mental effort was indexed through heart rate variability (HRV), in line with recent flow studies (Tozman et al., 2015; Peifer et al., 2014). See Chapter 4 (4.2.3) for full details.

5.2.3.6 Gaze variability. Based on the changes in gaze variability found in study 3 (Chapter 4), variability of fixation location (i.e. standard deviation of horizontal position) was again used to indicate driver distraction (Wilson et al., 2006). See Chapter 4 (4.2.3) for full details. Additionally, fixation rate was used as a more general index of visual attention, as a higher rate indicates an inefficient gaze strategy (Janelle, 2002; Wilson et al., 2006).

5.2.3.7 Eye-steering coordination*.* To develop the measures used in Chapter 4, and further understand psychophysiological changes during flow, eye-steering coordination was used as a measure of gaze-motor synchronization (see figure 5.2). Previous research has illustrated that gaze drives action in a variety of tasks with eye movements leading hand movements (Land, 2006). Visual attention to the cornering tangent point is crucial for negotiating bends during driving (Land & Lee, 1994) with the eyes moving to the apex of the corner around a second before the hands move the wheel (Yekshatayan & Lee, 2013). Highly coordinated gaze and wheel movements represent an optimal strategy (Chattington, et al., 2007), with reduced coordination indicative of inattention (Yekshatyan & Lee, 2013). The coordination is assessed through the time lag between eyes and wheel, and the subsequent correlation between the two signals (*r*). A higher correlation between eye movements and hand movements indicates that gaze is driving motor performance in a more effective way (Chattington et al., 2007).

5.2.3.8 Steering entropy*.* To examine whether changes in visual attention during flow, found in Chapter 4, extended to changes in motor control a measurement of steering wheel movements was obtained using a potentiometer. Sample entropy was used to assess the complexity of steering wheel movement. Entropy in general relates to rate of information production, and in a biological time series relates to randomness or complexity. Sample entropy is calculated from the natural logarithm of the conditional probability that a series similar for *n* points remains similar at the next point (see Richman & Moorman, 2000). Sample entropy is robust to variations in sample size. Measurements of higher entropy (in *bits*) would suggest a more complex steering strategy, most likely with more corrective movements.

5.2.4 Procedure

Participants attended one testing session for approximately one hour. They first read the information sheet and had the experiment explained verbally before signing the consent form. Overall participants completed 5 races on the simulator; in each race, participants were required to complete two laps of a moderately difficult racecourse as a time trial (i.e. no opponents), with racing settings standardised across all races and participants. The race was taken from the 'matched' condition in Chapter 4, as it was successful in creating an optimal challenge-skill balance, allowing flow-like performance to occur. This also facilitated comparison between studies.

Three familiarization races were conducted, the first two without eye tracking and heart rate equipment. Before the third race participants put on the SMI eye tracking glasses, the Polar heart rate strap and placed their head in the chin rest to allow familiarization with the equipment prior to the test races. Participants were then randomly assigned to either internal or external focus instructions in a counterbalanced design. Prior to the first test race the SMI eye tracking glasses were calibrated over three points across the television screen, and the tracking was then checked over a variety of markers across the screen.

Participants were then read instructions for either an internal or distal external focus. Internal focus: '*As you drive, keep your eyes on the road and maintain your focus on your hands on the steering wheel. This should help you steer more smoothly*.' External focus: '*As you drive, keep your eyes on the road and maintain your focus on where you are heading. This should help you become less distracted.* ' Instructions were designed to induce an internal/external focus, while still allowing the internal instructions to be task-relevant. A reminder of the focus of attention was given at the half-way point of each race (start of lap 2).

Following each of the test races participants completed the Flow Short Scale and manipulation check questionnaires. At the end participants were debriefed and allowed to ask any questions regarding the study.

5.2.5 Data Analysis

Gaze data was downloaded from the SMI ETG to BeGaze 3.6 software for analysis, allowing raw csv data to be extracted from the gaze video. Gaze videos were checked for recording quality, with videos that displayed a poor calibration removed from the analysis (2 participants).

Data processing was conducted in Matlab (2016a) with all raw data assessed for quality and artefacts removed. To compute time lag and cross-correlation in eye-steering coordination, x-axis gaze coordinates and wheel movements (in degrees) were time locked and filtered using a lowpass moving average filter. The cross-correlation function measures the degree of similarity across shifted sequences of the corresponding vector, as a function of the time lag. The peak lagged correlation indicates the average time lag between eyes and wheel, and *r* the degree of correlation between the signals. Sample entropy of the de-noised wheel signal was then calculated, using a tolerance of 0.2*standard deviation of the sample (Richman & Moorman, 2000).

Statistical analysis was performed using JASP (Love et al., 2015). Dependent variables were analysed using paired t-tests to compare internal and external conditions, with Wilcoxon signed rank test used when data deviated from normality. Bayes Factors (BF_{10}) were also obtained using a symmetric Cauchy prior. Bayes factors were included as an alternative to p-values to allow a more informed interpretation of effects, not based wholly on significance. BF_{10} indicates the relative probability of the obtained data under the two hypotheses (or prior odds). Factors of 3-10 indicate moderate evidence for the alternative, and 10+ strong evidence. In order to make firmer conclusions about any null effects, equivalence testing was used. This allows an inference about whether groups are equivalent, when no difference is found. Two one-sided t-tests were conducted using the TOSTER package for R (Lakens, 2017), which uses one-sided t-tests to test the null hypothesis that an effect exists which is greater than a specified effect size (*d*=0.3).

5.3 Results

5.3.1 Group comparisons

Participants who reported a difficulty in maintaining the instructed attentional focus (scores of 3 or below on the manipulation check) were removed from the analysis (*n*=3).

A Mann-Whitney U one sample test indicated a significant preference for an external focus (M=7.82, SD=2.86, comparison value=6), *V*(32)=304.00, *p*=.006, *d*=0.62, BF_{10}=18.25.

5.3.2 Self report.

Paired t-tests and Wilcoxon signed-rank test were used to compare self-report scores between experimental conditions. There were found to be significantly higher ratings of flow experience in the external condition (*M*=46.88, *SD*=7.85) than the internal condition (*M*=32.91, *SD*=11.81), *W*(29)=525.50, *p*<.001, *d*=1.78, BF_{10}=6.72*10^8. Likewise there were significantly higher ratings of outcome expectancies in the external condition (M=12.41, SD=2.63) than the internal condition (*M*=11.97, *SD*=3.51), *t*(28)=2.22, *p*=.04, *d*=0.41, BF_{10}=1.63. However there was no difference in self-reported effort (RSME) between external (*M*=59.60, *SD*=29.29) and internal (*M*=59.70, *SD*=29.97) conditions, *t*(29)=0.96, *p*=.35, *d*=0.17, BF_{10}=0.30. One sided tests indicated that the groups could not be considered equivalent, as an effect larger than *d*=0.3 could not be rejected (upper bound, *t*(29)=-0.69, *p*=.25; lower, *t*(29)=2.60, *p*=.007).

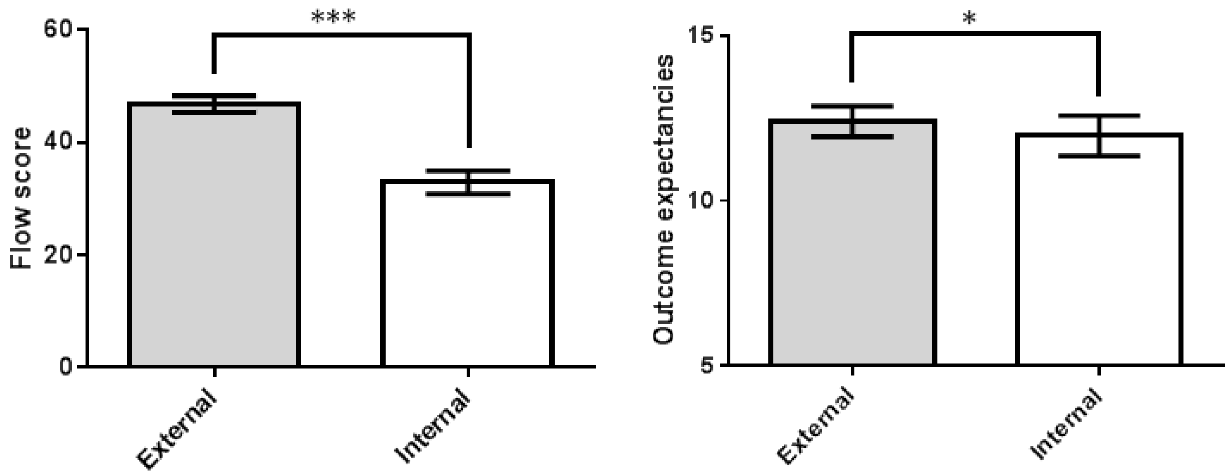


Figure 5.1; Group means (and standard error) of flow and outcome expectancy scores. *p<.05, ***p<.001

5.3.3 HRV.

There was found to be no difference between external (*M*=62.48, *SD*=15.20) and internal (*M*=61.90, *SD*=16.86) conditions in low frequency power (%), *t*(17)=0.26, *p*=.80, *d*=0.06, BF_{10}=0.25. One sided tests indicated that an effect larger than d=0.3 could not be rejected (upper bound, *t*(17)=-3.04, *p*=.004; lower bound, *t*(17)=-0.49, *p*=.69). There was also no difference between external (*M*=30.07, *SD*=14.77) and internal (*M*=31.89, *SD*=16.72) in high frequency power, *t*(17)=0.23, *p*=.82, *d*=0.05, BF_{10}=0.25, but groups were not equivalent (upper bound, *t*(17)=-1.39, *p*=.09; lower bound, *t*(17)=1.16, p=.13).

5.3.4 Driving performance.

Paired t-tests were used to assess the effect of attentional focus instructions on performance measures. There was found to be no difference in performance (seconds) between external (*M*=260.80 *SD*=32.17) and internal (*M*=254.40 *SD*=57.99) conditions, W(28)=249.00, *p*=.30, *d*=0.09, BF_{10}=0.22. One sided tests indicated that an effect larger than d=0.3 could not be rejected (upper bound, *t*(28)=-1.15, *p*=.13; lower bound, *t*(28)=2.08, *p*=.02).

5.3.5 Gaze variability.

There was found to be no difference in gaze variability (SD of x-coordinates) between external (*M*=110.7 *SD*=30.34) and internal (*M*=113.5 *SD*=29.95) conditions, *t*(27)=0.54, *p*=.59, *d*=0.10, BF_{10}=0.23. One sided tests did not suggest equivalence (upper bound, *t*(27)=-1.05, *p*=.15; lower bound, *t*(27)=2.13, *p*=.02). For fixation rate (fixations per second) there was also no difference between external (*M*=1.84 *SD*=0.33) and internal (*M*=1.82 *SD*=0.31) conditions, *t*(27)=0.46, *p*=.65, *d*=0.09, BF_{10}=0.22. Again one sided tests did not show equivalence (upper bound, *t*(27)=-2.87, p=.03; lower, *t*(27)=1.13, p=.14).

5.3.6 Eye-steering coordination

There was no difference in eye-steering correlation (*r*) between external (*M*=.64 *SD*=0.19) and internal (*M*=.61 *SD*=0.21), *W*(27)=213.00, *p*=.83, *d*=0.12, BF_{10}=0.24. One sided tests indicated that an effect larger than d=0.3 could not be rejected (upper bound, *t*(27)=-2.20, *p*=.02; lower, *t*(27)=0.98, *p*=.17). There was also no difference in time lag between external (*M*=1.28 *SD*=0.30) and internal (*M*=1.26 *SD*=0.28), *t*(27)=0.28, *p*=.78, *d*=0.05, BF_{10}=0.21. One sided tests indicated that an effect larger than *d*=0.3 could not be rejected (upper bound, *t*(28)=-1.87, *p*=.04; lower, *t*(28)=1.31, *p*=.10).

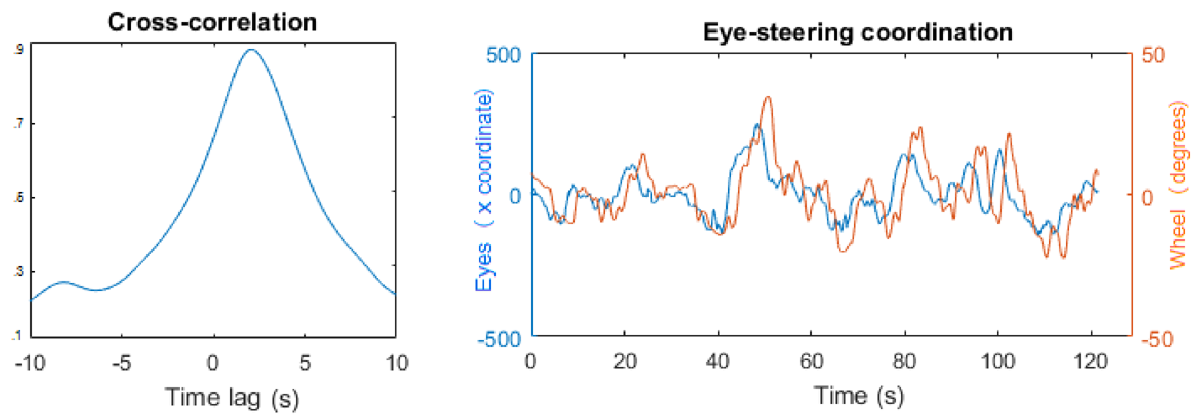


Figure 5.2; eye-steering coordination for a single race. Panel A) (left) shows the peak correlation across time lags, Panel B) shows superimposed gaze and wheel signals.

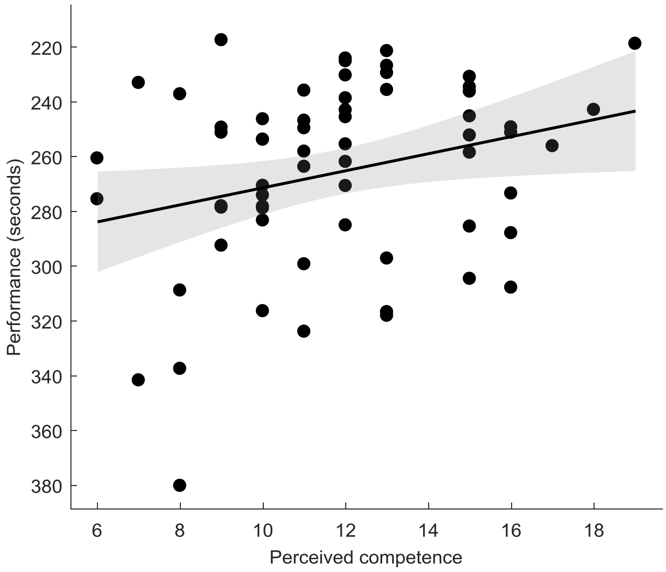
5.3.7 Steering entropy

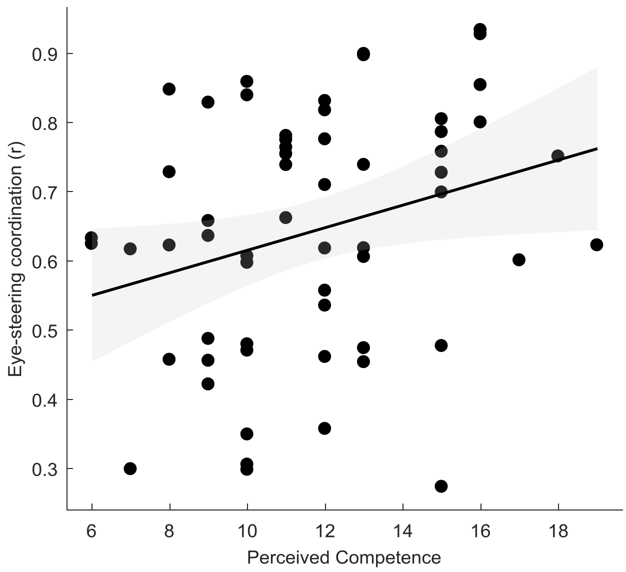
There was no difference in steering wheel entropy between external (*M*=0.06, *SD*=0.02) and internal (*M*=0.06, *SD*=0.02) conditions, *t*(27)=-1.10, *p*=.28, *d*=.208, BF_{10}=0.35. One sided tests did not show equivalence (upper bound, *t*(27)=-2.69, *p*=.006; lower bound, *t*(27)=0.49, *p*=.32).

5.3.8 Correlations

Correlation analysis was used to examine the relationship between flow and other outcomes, across both conditions. There was found to be a significant relationship between flow and performance times, *r*(62)=-.31, *p*=.01, BF_{10}=3.30, and flow and self-efficacy, *r*(63)=.30, *p*=.02, BF_{10}=2.70.

Correlation analysis was also used to explore the relationship between perceived competence and performance markers. There was found to be a significant relationship between perceived competence and performance times, *r*(63)=-.27, *p*=.03, BF_{10}=1.53. Perceived competence was also related to reduced fixation rate, *r*=-.29, *p*=.03, BF_{10}=1.85, steering entropy, *r*=.32, *p*=.01, BF_{10}=0.99, and eye-steering coordination, *r*=.28, *p*=.03, BF_{10}=1.49 (see figure 5.3).





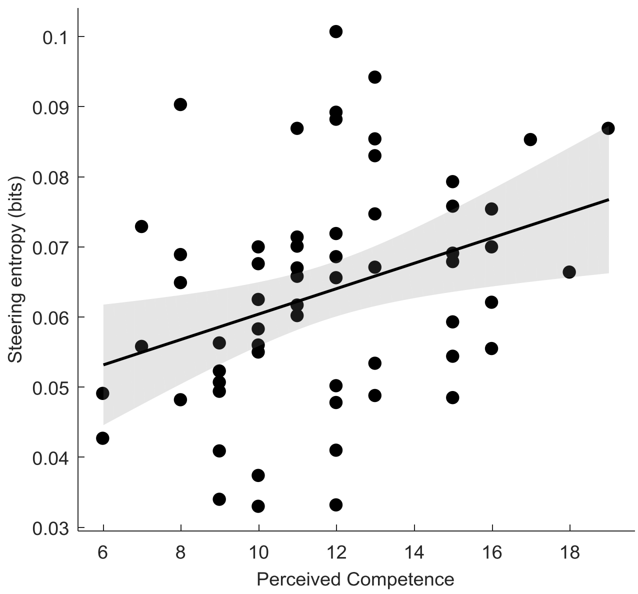


Figure 5.3; Relationship between perceived competence and A) Performance (r=.27, top); B) Eye-steering coordination (r=.28, middle); C) Steering entropy (r=.32, bottom)

5.4 Discussion

Focused attention is described as a core component of the flow experience (Csikszentmihalyi, 1990), with recent neuroimaging and eye-tracking findings indicating that during flow, top-down attentional processes are strongly engaged (Ulrich et al., 2016; Yoshida et al., 2014), while focus on the self may be inhibited (Ulrich et al., 2014). Experimental manipulations of attention can test whether attention changes are merely an outcome of flow, or have a causal effect. Additionally, simple manipulations of attention may provide practical applications for athletes to experience flow more frequently. Therefore this study sought to examine whether an attentional focus manipulation could facilitate flow experience in a simulated driving task.

In line with our primary hypothesis, external focus instructions lead to greater self-reported flow. This manifested as a large effect (d=1.78) indicating an appreciable difference, and Bayes Factor of >100, indicating that the data obtained were much more likely under the alternative hypothesis. This finding has implications for understanding the mechanisms behind flow as previous research has mostly *associated* attention changes with flow experience (Swann, Crust & Vella, 2017). The current finding however, points to a causal direction; appropriate focusing of attention, may lead to the experiential state. Flow is often described as a strong focus on the task and away from the self (Jackson & Csikszentmihalyi, 1999). Here focusing externally appears to have had a causal influence on the experience of flow. In combination with the findings from Chapter 4 and previous flow research (Ulrich et al., 2016), activity of higher attention networks and enhanced attention control may be important causal mechanisms. If future research supports this conclusion, it has important implications for theory and practice. Firstly, there is no convincing theoretical framework within the flow literature that describes the proximal causal mechanisms of flow. Dietrich's hypofrontality theory could be considered such an approach, but as discussed in this thesis (see 1.2.1.6) recent findings are at odds with a state of hypofrontality (Yoshida et al., 2014; Harmat et al., 2015). A mechanism based on attention control may provide an alternative. Following from this, if a causal influence of attention is supported it provides opportunities for applied interventions to promote flow.

Any changes in flow following the manipulation were predicted to be a result of automated motor control (steering wheel entropy) and goal-directed visual attention (eye-steering coordination and gaze variability), but this hypothesis was not supported. There were no significant group differences in these measures, with Bayes factors ranging from 0.23-0.35, suggesting weak support for the null. One-sided tests, however, did not indicate groups to be equivalent, so the evidence is inconclusive, rather than supportive of no difference. The lack of an effect may be due to participants not reaching the highest levels of flow. Mean scores per item were 4.69 (external focus) and 3.29 (internal focus), which are just above and just below the mid-point of the scale respectively. This suggests participants may not have reached a high level of flow overall, as previous work with this scale by Engeser and Rheinberg (2008) obtained scores of up to 5.9[9] in a gaming task. Moderate flow scores for both groups may explain the lack of gaze and motor control differences. The lack of a

[9] Raw scores were 2.1, which is equivalent to 5.9 on the inverted scoring used in this study.

performance effect is perhaps surprising, given previous findings relating to attentional focus manipulations (Wulf, 2013), but may well be a consequence of the gaze and steering results.

To validate findings from Chapter 4, which indicated flow to be linked to effortful focusing of attention, the same gaze variability and effort measures were included here. The difference in flow between conditions did not extend to differences in perceived or objective effort, nor to differences in gaze variability. As discussed, the influence of the manipulation may not have been sufficient to overcome the effect of the inherently engaging task, as flow scores remained high in both conditions. This could be responsible for the gaze and effort effects not extending to this manipulation. Alternatively, the findings from Chapter 4 may have been specific to the difficulty manipulation used.

It was also predicted that an external focus of attention would lead to enhanced expectancies, based on the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). This prediction was marginally supported (p=.04) with a small to medium effect (d=0.41). A Bayes factor of 1.63, however, provides little support for the alternative hypothesis over the null. A difference in outcome expectancies is in line with the results of Pascua et al. (2015) who found external focus instructions to enhance self-efficacy in a tennis ball throwing task, but only at a subsequent retention test. The OPTIMAL theory suggests that enhanced self-efficacy expectations and an external focus both benefit motor learning and performance, which in turn creates a feedback loop leading to further enhanced expectancies. However, as there was no evidence of performance improvement as a result of the manipulation, the effect of attentional focus on enhanced expectancies may have been through a more direct route, rather than feedback from performance.

A second group of predictions suggested that enhanced expectancies would be related to flow, performance and markers of attention and motor control, which were largely supported. Enhanced expectancies may be strongly tied to the *mastery experience* of challenge-skill balance in a task (Bandura, 1993), and has been linked to performance benefits through enhanced attention control (Themanson & Rosen, 2015). As a result, it may contribute to the state of focused performance during flow. In line with previous findings (Swann et al., 2012; Koehn, 2013) there was a statistically significant, but relatively weak, relationship between flow experience and outcome expectancies, and between outcome expectancies and performance (Bouffard-Bouchard, 1990; McMay et al., 2012). Of greatest note were the relationships between outcome expectancies and fixation rate, eye-steering coordination and steering entropy. A reduced fixation rate suggests a more effective gaze strategy (due to saccadic suppression) and is indicative of top-down attention control (Janelle, 2002). Similarly the degree of eye-steering coordination is a functional gaze-action coupling for negotiating corners (Chattington et al., 2007), which impairs performance when disrupted (Marple-Horvat et al., 2005), and indicates good attention during driving (Yekshatayan & Lee, 2013). Entropy in biological time series data is indicative of complexity or randomness (Richman & Moorman, 2000), and here may indicate smaller, more frequent, corrective movements characteristic of automated motor control, as has been found in frequency domain analyses in balance tasks (McNevin, Shea & Wulf, 2003; Wulf, McNevin & Shea, 2001)[10]. In combination, these measures indicate focused attention, automated motor control and an improved functional coupling between the two. It should be acknowledged that these were relatively weak relationships (circa r=.30), but as a link between mere belief in outcome and precise measures of gaze-action coupling these results are nonetheless noteworthy. Overall, these findings indicate that outcome expectancies may indeed link to flow, performance and positive changes in attention and motor control.

In summary, the effect of attentional focus on flow experience found here suggests opportunities for finding flow in a variety of sporting, leisure and work settings. Within sport, an external focus of attention may not only provide the established motor control benefits (Wulf, Höß & Prinz, 1998; Wulf, 2013), but

[10] Boer (2000) has previously linked increased steering entropy to reduced steering smoothness, but crucially this was during 'non-taxing' driving conditions where corrective movements indicate an error has occurred. As this was a racing task, and smooth steering would only occur if a participant was driving very slowly, corrective movements were interpreted as functional, in line with previous work in balance tasks (Wulf, McNevin & Shea, 2001).

promote an experiential state similar to flow. Given the importance of goal directed attention in flow (Ulrich et al., 2016) techniques for long-term training of attentional abilities may enable more frequent flow experience. For instance computer-based attention training tasks may enhance executive abilities, although benefits tend to have limited generalisability (Tang & Posner, 2009; Ducroq et al., 2016). Alternatively, gaze training programmes like quiet eye training (Vine, Moore & Wilson, 2011) promote good visual attention control (Vine & Wilson, 2011) and an external focus (Moore et al., 2012), and can be implemented as a sport specific intervention. Quiet eye training may also contribute to enhanced outcome expectancies, as Wood and Wilson (2012) found a quiet eye trained group to not only improve their attention control in a soccer penalty task, but also showed increased perceptions of competence and reduced outcome uncertainty.

A limitation of this study relates to the highly engaging task, which may have reduced the effects of the attentional focus manipulation. An immersive task was chosen so that flow-like experiences had the best chance of occurring, however flow scores indicated participants were still highly engaged, despite an internal focus of attention. Therefore any potentially disruptive effects of an internal focus on motor control and eye-steering coordination may have been mitigated by the focused concentration that was still present. The driving task was also more complex than many used previously to investigate attentional focus (Wulf, 2013), so future studies to confirm the effect of attentional focus on flow may wish to make use of more traditional balancing or throwing tasks. An additional limitation is the wording of the external focus instructions. Participants were directed to the hands on the wheel (internal) or the direction of heading (external). However, they were also asked to maintain their gaze on the road, to avoid confounding the eye-movement analyses through cueing participants to look at their hands. This may have added an additional external element to both groups, reducing any effects of the manipulation.

5.4.1 Conclusions

There is growing research indicating cognitive changes during flow experience, principally indicating attention to be task-focused and directed away from the self (Ulrich et al., 2016; Chapter 4). The current attentional focus manipulation elicited increased flow experience, showing attentional changes to have a causal effect on flow. Additionally, outcome expectancies were found to relate to both flow and improved visual attention control. Both the effect of the attentional focus instructions and the findings pertaining to outcome expectancies suggest practical benefits for finding flow through attention focusing and training techniques.

6. Chapter 6

6.1 General Discussion

6.1.1 Summary of key findings

While much flow research points to the focused concentration that characterises the state (Jackson & Csikszentmihalyi, 1999; Ullén et al., 2010; Swann et al., 2012), there has been only limited research addressing specific attentional mechanisms (Ulrich et al., 2016), and no research in the sporting domain utilising objective measures of attention. Therefore the purpose of this thesis was to examine whether the experience of flow was linked to measureable changes in attention (aim 1). In particular whether flow was linked to sport-specific measures of attention control (Chapters 2 and 3), how flow relates to attentional effort (Chapter 4), and whether manipulations of attentional focus can predispose people to finding flow (Chapter 5). Additionally, an overarching aim was to develop an experimental approach to flow (aim 2), which is lacking within the sporting domain.

Chapter 2 aimed to investigate a possible relationship between attention control and flow. Experiment 1 reflected the aim of examining the relationship between attention control and flow. It was predicted that trait attention control differences may predict individual propensity to attain flow; this was supported but with a relatively weak relationship. This indicates that while attention control contributes to the 'autotelic' personality, there are other major factors to consider. Based on this relationship, experiment 2 aimed to further examine the relationship between attention control and flow, but also develop an experimental method, in line with the second aim of the thesis. It was hypothesised that individuals with better attention abilities (measured in terms of trait mindfulness) would be more likely to experience flow in a basketball task. Results provided no support for this conclusion. To investigate attention control through objective measures (that is, not self-report), quiet eye durations were assessed during the basketball task. There was found to be no relationship between flow and quiet eye, which may have been influenced by the use of novice basketball players. Limited conclusions can be drawn from this study in relation to aim 1 given some methodological difficulties, but this was an important first step in developing experimental approaches to flow in sport (aim 2), that contributed to subsequent studies in the thesis.

In line with aim 2, to improve upon on the methodological approach of Chapter 2 (expt. 2), Chapter 3 used an alternative flow measure, allowing a greater frequency of measurement, and recruited basketball and netball players that may be more likely to achieve flow, given their proficiency in the task (Canham & Wiley, 2003). Chapter 3 also used a graded manipulation of challenge across 5 levels, allowing for greater variation in flow, instead of the flow/no-flow instructions in Chapter 2. As in Chapter 2 (expt. 2) there was found to be no effect of the challenge-skill balance manipulation on flow. In relation to aim 1 of the thesis, the prediction that flow experience would be related to improved attention control was supported through a weak relationship between self-reported flow and QE duration, providing evidence that the subjective state of flow may be accompanied by objective changes in visual attention. These findings again highlight the difficulties of the experimental approach (aim 2), but indicate that gaze behaviour may provide a useful measure of attentional changes during flow.

Chapter 4 again aimed to develop the experimental methodology, in line with aim 2 of the thesis. While Chapters 2 and 3 had used a manipulation of the *perceived* challenge-skill balance, Chapter 4 altered the objective task demands. This was found to create significant differences in flow, with a moderately challenging task facilitating greater flow than 'too easy' or 'too hard' tasks. Chapter 4 also utilised a computer gaming task, to provide a maximally absorbing activity, which still replicates many of the demands of sport. An alternative measure of attention control was also used to extend previous findings, with flow found to be related to reduced gaze variability. Also, predictions regarding reductions in felt effort during flow were tested, indicating a dissociation between objective and subjective effort. Flow is often reported as feeling 'effortless', but this is the first study to show how felt and observed effort might diverge across different levels of challenge. A model was proposed to explain this dissociation, based on previous theories. Overall the results suggest flow to be a state of focused attention and increased mental effort, but with reduced awareness of that effort, informing conclusions relating to aim 1 of the thesis.

As Chapters 3 and 4 suggest attentional changes during flow, Chapter 5 aimed to test whether attention has a causal effect on flow experience, to allow clearer conclusions to be drawn about the relationship between flow and attention control (aim 1). It was predicted that an external focus of attention would lead to increased flow experience due to improved motor automaticity and gaze-motor coordination. This was partly supported as there was found to be an increase in flow, but there was no effect of attentional focus on gaze/motor measures. These findings suggest that attention is indeed a driving factor behind flow, indicating that the changes in attention control found in Chapter 4 could be a causal mechanism. Additionally, the role of outcome expectancies as a contributory psychological process was examined. Outcome expectancies may be strongly tied to the optimal challenge that is necessary for flow, and have previously been linked to attentional control (Themanson & Rosen, 2015) and cognitive effort (Bandura, 1993), suggesting they may contribute to the state of focused attention during flow. This relationship was supported, with perceived competence being linked to both flow and indicators of good attention control (gaze variability and eye-steering coordination). As such, the increase in outcome expectancies that come from challenging situations may contribute to the attentional state during flow. These findings have implications for applied interventions. Firstly, interventions promoting positive beliefs about future outcomes should be beneficial, as previous studies have highlighted the importance that athletes ascribe to confidence for inducing flow (Stavrou & Zervas, 2004; Swann et al., 2012). Secondly, the causal influence of attention found here shows that interventions to improve attention, either momentarily or through long-term training, may enable athletes to find optimal states, like flow, more frequently.

Overall, the four studies of this thesis examined the role of attention during flow, contributing novel findings to the literature. Key findings are firstly, that flow is linked to objective changes in visual attention, secondly that this attention is effortful but may not be experienced as such, and thirdly that attention has a *causal* effect on flow. Additionally these studies attempted to develop experimental approaches used in simple gaming tasks to more sport-relevant activities. The relationship of these findings to previous studies and implications for theory, practice and future research are discussed below.

6.1.2 Implications of key findings

6.1.2.1 Role of attention control

The main findings from this series of studies relates to the role of attention control, which this thesis proposes as an important proximal mechanism behind the experience of flow. Chapter 2 provided initial evidence that trait differences in flow proneness may relate to attention control ability, while the gaze control findings of Chapters 3 and 4 provide the first overt measures of attentional changes during flow. Chapter 3 indicated that flow may be related to changes in relative quiet eye duration, which has been discussed as an instance of optimal visual attention (Vine & Wilson, 2011; Wilson, Vine & Wood, 2009). The balance between task relevant (top-down) and disruptive, task-irrelevant attention (bottom-up) determines attention control (Corbetta & Shulman, 2002; Knudsen, 2007), and this interaction reflects one proposed function of the quiet eye, to allow a period of response programming, while minimizing distraction from other environmental stimuli (Vickers, 1996; Vine & Wilson, 2011). The effect found was weak (r=.20), but in trying to relate the subjective experience to measurable changes in eye movements this may not be surprising.

Additionally this finding is in line with traditional descriptions of the flow experience as consisting of focused concentration with immunity to distraction (Jackson & Csikszentmihalyi, 1999; Swann et al., 2012). Effective attention control during flow also aligns with the association between flow and performance (Jackson et al., 2001; Koehn & Morris, 2012, see below), as focused attention in sporting tasks has been consistently linked with performing well (Mann et al., 2007; Eysenck & Wilson, 2016). This is due to top-down control directing gaze and attention to the most relevant parts of the visual scene allowing key information to be obtained (Memmert, 2009), and avoiding wasteful or detrimental processing of irrelevant cues. As such the findings of Chapters 2 and 3 provided tentative evidence of a relationship between improved attention control and flow.

Chapter 4 similarly suggested good attention control during flow, as indicated by a reduced variability of eye movements during simulated racing driving. A high degree of gaze variability represents an inefficient gaze strategy (Janelle, 2002) with previous research finding anxiety-induced increases in variability of horizontal eye movements and subsequent performance impairments during driving (Wilson et al., 2006). A functional reduction in variability is also seen under mental load, as gaze becomes concentrated on the road (Recarte & Nunes, 2000). Across three levels of challenge, the matched-to-skills race produced the greatest flow experience and most focused gaze, supporting the role of the challenge skill balance in flow (Engeser & Rheinberg, 2008; Fullagar, Knight & Sovern, 2013). As increased variability is linked to disrupted attention during anxiety (Wilson et al., 2006), this focusing of gaze was interpreted as an indication of improved attention control. During the easy drive this level of attention control was not required (mirrored by the effort findings), and notably during the hardest drive, attention was again less focused as flow experience was diminished. Therefore gaze variability did not just respond to the task demands, but was related to the individual's experience of flow. Further, the increase in mental effort found during the matched-to-skills level supports the role of attention control, a cognitively effortful function (Sarter, Gehring & Kozak, 2006). These results support the flow – QE relationship found in Chapter 3, suggesting a general improvement in visual attention is related to flow, across netball, basketball and driving, as opposed to a task specific effect. Clearly this finding needs to be extended across more tasks, but there is supportive evidence from neuroimaging studies to suggest that activation of top-down attention control networks may be a general effect during flow.

Ulrich et al. (2016) found that during optimally challenging levels of an arithmetic task, areas of fronto-parietal cortex displayed increased activation, linking the pattern of activity to the Multiple Demand (MD) network (Duncan, 2010). The MD network is a functionally general system responsible for goal-directed behaviour, fluid intelligence and visual attention. Similar to the flow and focused gaze findings in Chapter 4, Ulrich and colleagues found peak activation to be at moderate challenge, not a higher level of difficulty. The activated areas also overlap with Corbetta and Shulman's (2002) dorsal network. Similarly the role of dopamine in flow proneness suggests that response inhibition and reduced impulsivity contribute to flow (Gyurkovics et al., 2016), important factors in executive attention control (Miyake et al., 2000). While the tasks that can be used in neuroimaging research have a limited generalizability to sporting tasks, this line of evidence converges with the findings of this thesis in outlining a role for traditionally effortful processes of attention control that have perhaps been overlooked due to a focus on the ease and automaticity often linked with flow.

Dietrich's (2003; 2006) hypofrontality theory of flow emphasises a move to automaticity in flow and a reduction in prefrontal functions, including effortful attention control (Miyake et al., 2000). This dominant view in the literature of flow as easy and automatic (Swann et al., 2016) is somewhat at odds with the growing evidence for the role of effortful attention control, as automaticity is essentially the absence of controlled attention. Neuroimaging findings have not supported the general hypofrontality proposed by Dietrich (Yoshida et al., 2014; Harmat et al., 2015), with reduced prefrontal activity restricted to areas like medial PFC which relate to self-awareness. Findings of increased mental effort in Chapter 4 - in line with previous results (Keller et al., 2011; Peifer et al., 2014; Tozman et al., 2015) - indicates that effortful mental processes must be engaged. However a role for automaticity is consistent with pervasive reports of ease during flow (Swann et al., 2016). These ideas are reconcilable, as flow may be a state of enhanced automaticity of motor control (with the associated benefits of neural efficiency, Wolf et al., 2015), but with some effortful engagement of task relevant attention. Indeed Csikszentmihalyi and Nakamura (2010) postulate that the importance of automaticity during flow lies in allowing automated sequences to take care of themselves, so that *more* attention can be paid to other (more strategic) aspects of the activity.

An alternate theory discussed previously is Weber et al.'s (2009) neural synchronisation theory, which suggests that flow is a result of widespread synchronisation of executive, alerting and orienting attentional networks. While there is no direct evidence for an increased synchronisation of neural firing rates during flow, this theory is consistent with both findings of mental effort and increased top-down control. As such, current theories relating to flow mechanisms are still lacking, but may depend on continued research focus on psychophysiological indicators of cognitive changes. Evidence suggests that a comprehensive theory should account for both the focused concentration of top-down control and the efficient motor performance of automated processing.

Overall the findings of this thesis have important implications for our understanding of attention during flow. Firstly, the direct measures of attention used here support key dimensions of Csikszentmihalyi's description of flow. The dimension 'concentration on the task at hand' indicates that during flow attention is task focused. Findings that flow may be related to improved QE and more focused gaze in driving indicate that people were indeed concentrated on the task at hand. Additionally the dimension 'action-awareness merging' describes how during flow people are so engaged that they experience their actions as spontaneous. The gaze findings again support that, during flow, people were highly involved in the task, and the dissociation of reported and observed mental effort in Chapter 4 supports the feelings of ease that may accompany this absorption. In particular, the findings from this thesis have important implications for our understanding of flow as they provide the first overt measures of attention changes that underpin the subjective experience of concentration and focus during flow. This also indicates that objective changes in cognitive processes occur during flow, rather than being merely a retrospective reporting bias.

Some key questions remain, however, regarding how and why this state of focused attention is only occasionally found. The challenge skill-balance is clearly important in engaging good attention control; when challenges are low a high degree of cognitive control is not needed to meet task demands and when challenges are too high overload and anxiety may disrupt good attention. However, instances of challenge-skill balance often occur without the intense focus of flow, so other factors are influencing whether this optimal attention state is reached. As identified within sport research, this may include factors like confidence, arousal and motivation (Swann et al., 2012). Understanding why this state of attention can be found in some instances but not others is surely one of the ultimate goals of flow research, so that athletes, workers and people engaging in leisure activities are able to more frequently make use of the focused state of flow.

6.1.2.2 Role of attentional effort

A second novel finding is the dissociation of objective and subjective measures of attention found in Chapter 4. The role of mental effort is germane to our understanding of attention, as it is indicative of the type and amount of cognitive processing occurring, and informs the debate regarding automated and controlled processing during flow. As discussed, automated processes are exempt from mental effort, but higher order, executive functions are generally associated with increased effort (Sarter et al., 2006). While not identified as one of Csikszentmihalyi's experiential flow dimensions, the *effort paradox* of flow (Bruya, 2010) is potentially a defining feature of the state, as it seems to present an attentional anomaly; increased demands are met with a seeming decrease in effort. Chapter 4 sought to address whether the oft-reported ease during flow (Swann et al., 2016) could be seen to dissociate from an objective level of effort.

Across three levels of challenge, subjective effort was seen to increase linearly from easy to matched (C-S balance) to hard, as expected, but heart rate variability indicated an inverted-U shape, suggesting greatest mental effort in the matched condition. This is in line with previous studies that have found elevated effort and arousal in a matched/flow condition (Tozman et al., 2015; Peifer et al., 2014), however these studies did not take a corresponding subjective measure of effort. Traditional theories of effort suggest that invested effort is proportional to task demands (Kahneman, 1973), but this was not found to be the case here, with the hardest level and easiest level extracting similar levels of effort. In order to better understand the effort paradox of flow, a model was proposed based on a combination of Motivational Intensity Theory (Wright, 1996) and Botvinick and colleagues' Conflict Monitoring Hypothesis. Motivational Intensity Theory suggests that invested resources are proportional to task demands, but may be withdrawn when chances of success are appraised as being low. Meanwhile the Conflict Monitoring Hypothesis describes how appraised conflict and a change in cognitive control is experienced as cognitive effort. In combination this suggests a maximal investment of effort during flow, as task demands are high but reachable; however no change in cognitive control is necessary, so little effort is experienced. There may be some neuroimaging support for this model, as Ulrich et al. (2014) found increased activation of the putamen during flow, an area previously found to be involved in goal-directed behaviour through coding outcome probability in relation to effort (Hori, Minamimoto, Kimura, 2009).

An additional reason why flow may feel effortless is the focus of attention adopted. Athletes in flow describe how they were only focused on the task and not on themselves (Jackson & Csikszentmihalyi, 1999), a suggestion backed up by neuroimaging results. Ulrich et al. (2016) found reduced activity of the medial PFC, an area linked to self-referential processing, while Ulrich et al. (2014) found additional areas of the default mode network, linked to mind wandering and thoughts about the self, to be inactive during flow. As such during flow there seems to be a move away from internal focus and towards a focus on the task and it's outcomes. Focusing externally, on movement effects, has been shown to benefit movement efficiency and effectiveness (Wulf, 2013), with the principal mechanism for this effect proposed to be a move towards automaticity of motor processing (Kal, van der Kamp, & Houdijk, 2013; Lohse, 2012; Wulf, McNevin, & Shea, 2001). This external focus allows the motor system to self-organise without the disruptive effects of self-focus (Wulf & Lewthwaite, 2010). This efficiency of movement through an external focus of attention may contribute to the reduction in felt effort during flow (Wulf & Lewthwaite, 2010).

The attentional focus manipulation of Chapter 5 indicated that focusing externally did indeed lead to enhanced flow experience, although the degree of external focus during the experience was not measured. As quiet eye has been linked with focusing externally (Moore et al., 2012, although see Klostermann, Kredel & Hossner, 2014) the results of Chapter 3 may further indicate an external focus during flow, but again this should be interpreted with caution. The general reduction in self-awareness during flow, however, seems more certain (Csikszentmihalyi, 1990). Future research may wish to further examine this role of attentional focus in flow, as when combined with our previous discussion of subjective and objective effort it may contribute to an understanding of the effort paradox.

6.1.2.3 Role of performance

While not a direct aim of the thesis, the relationship between flow and performance was still a notable part of the studies, particularly given the sporting context. Some researchers note that flow is likely to benefit performance in the long term, as the intrinsic motivation obtained during flow means individuals are driven to engage in and practice their skill over and over (Engeser & Schiepke-Tiska, 2012; Schuler & Brunner, 2009). However, from both a theoretical and an applied perspective, a more direct effect on individual performances is of more interest. As discussed, previous research has consistently found a flow-performance link (Koehn & Morris, 2012; Stavrou et al., 2007), but the methodological approach of using interviews or questionnaires following peak performances leaves significant questions given the potential for retrospective bias (Brewer et al., 1991). Establishing a causal effect is challenging, something Stoll (2016) suggests as the most problematic claim in the flow literature.

The results of the studies in this thesis are, nonetheless, in line with previous findings of a flow performance relationship. Chapter 2 found no overall relationship between flow and basketball shooting performance, but curiously there was found to be a relationship in the group given the non-flow instructions ($r=.50$). Chapter 3 supported a relationship between flow and performance in basketball and netball ($r=.47$), as did Chapter 5 in driving ($r=.31$). In Chapter 4, using average speed as a performance metric indicates that fastest driving occurred in the condition with the greatest flow, but as task difficulty was manipulated this relationship is hard to interpret as supportive. This manipulation of task demands makes evaluation of a flow-performance relationship difficult, as is the case with several previous studies utilising levels of difficulty in gaming (Engerser & Rheinberg, 2008; Keller & Bless, 2008; Keller Bless, Blomann & Kleinbohl, 2011). Overall though, the results are in line with previous flow research (Koehn & Morris, 2012; Jackson et al., 2001).

Despite the adoption of experimental designs in the present studies, drawing conclusions about the causal nature of the flow-performance relationship is still not possible due to the dependency on self-report measures completed following task performance. To draw firmer conclusions regarding a causal effect of flow, experimental manipulations of feedback (knowledge of results) may be needed, to establish if higher ratings of flow co-occur with heightened performance even when participants have no knowledge of outcomes. This is experimentally demanding however, as eliminating all kinds of process feedback may not be possible. From a theoretical perspective, flow only occurs in the presence of clear goals and immediate feedback (Csikszentmihalyi, 1990), as without feedback there is no evaluation of the challenge-skill balance, and potentially no flow state. Consequently conclusive findings of a causal effect may elude researchers.

However, although these studies do not provide direct evidence of a causal effect on flow, a greater understanding of the attentional mechanisms responsible for flow outlines how improved performance during flow is highly likely. Quiet eye durations are a functional visual behaviour in aiming tasks (Vickers, 1996; 2007) and longer durations are linked to hit/miss outcomes and expertise/novice differences (Lebeau et al., 2016). As such, a longer quiet eye during flow is likely to be highly facilitative of performance. Likewise, the reduction in gaze variability found in Chapter 4 is reflective of functional gaze behaviour with scattered, unfocused gaze detrimental to driving (Janelle, 2002; Wilson et al., 2006). The eye-steering coordination measure in Chapter 5 was similarly chosen as a functional gaze behaviour (Land & Lee, 1994; Chattington et al., 2007; Marple-Horvat et al., 2005) but was not found to be related to flow. As an overall mechanism, increased top down control is strongly linked with improved performance across many real-world tasks (Mann et al., 2007; Schmeichel & Baumeister, 2010; Wilson, Wood & Vine, 2009; Vickers & Williams, 2007) and as such a state of optimal attention control during flow makes performance benefits almost inevitable.

The findings of this thesis, suggesting optimal attention control during flow, also have implications for how we relate flow to other states of peak or improved performance. Swann et al. (2016) found that after a golf tournament golfers experienced two distinct states during excellent performance, which researchers termed ‘letting it happen’ and ‘making it happen’, with flow equated to ‘letting it happen’ as performers felt ease, confidence and focused just on the process. In contrast, ‘making it happen’ states occurred when golfers knew they needed additional, deliberate, focus to achieve a specific goal, often at the end of a round when under pressure. Subsequently, Swann, Crust and Vella (2017) have also described these states as 'flow' and 'clutch', with flow being automatic performance, but clutch requiring a more conscious awareness of task demands. Traditional descriptions of the clutch state, however, use the term to indicate maintenance of performance under pressure (Otten, 2009). In the work of Swann et al. (2017) this element is largely ignored, and clutch is instead identified as an experience similar to flow, but more effortful and deliberate. In contrast, the results of this thesis would suggest the difference between these states may be very minimal. Chapters 3 and 4, argued that flow may very much require effortful, conscious and deliberative processing. If this is the case, the cognitive processes underlying optimal performance from both flow and clutch states may be very similar, with the perception of effort the main difference. It seems unlikely that, when engaged in complex team sports requiring constant decision making, being fully automatic and 'letting it happen' (Toner & Moran 2014) would lead to optimal performance. A more nuanced description of individual processes may be the answer, as automaticity of motor processes may well be crucial for flow, but more deliberative thought may be required for tasks like decision making. Therefore further investigation of the states of flow and clutch is warranted, to examine whether they can be considered truly distinct.

A notable contrast to the widespread belief in the beneficial effects of flow comes from research investigating flow and the 'runners high' (Stoll, 2016). Schuler and Brunner (2009) and Stoll and Lau (2005) did not find flow experience to link to improved performances in marathon running, suggesting that a sense of self, which drops away during flow (Dietrich, 2006), is required to dictate the pacing strategy. Indeed, these authors suggest that flow may actually be a hindrance. Flow might be beneficial in most sporting contexts when focusing on the task and away from the self is key (avoiding conscious processing) but when self-awareness is an important task component flow may not be optimal for performance.

6.1.2.4 Role of psychological variables

Various psychological processes may contribute to the experience of flow, but only outcome expectancies were investigated in this thesis, due to a theorized link with attention control (Themanson & Rosen, 2015). Previously, research has linked flow to psychological variables like intrinsic motivation (Keller & Bless, 2008), positive affect (deManzano et al., 2010), and an absence of anxiety (Koehn, 2013; Swann et al., 2016). Confidence, has been strongly identified by athletes as a precursor for flow (Swann et al., 2012), but may also be a consequence, given the role of challenging activities in creating mastery experiences (Bandura, 1993).

As one example of an enhanced outcome expectancy, self-efficacy has been found to be related to executive function, attention control and cognitive performance (Themanson & Rosen, 2015; Themanson et al., 2008; Jongen et al., 2015). In support of this, in Chapter 5 enhanced outcome expectancies (measured through perceived competence) were found to be related to reduced fixation rates and improved eye-steering coordination, both indicative of good attention control (Janelle, 2002; Yekshatayan & Lee, 2013). Further, outcome expectancies were related to steering wheel entropy, which may indicate automaticity through more frequent steering adjustment, although this is open to interpretation (see Boer, 2000). Given this relationship with attention, outcome expectancies may play an important role in enhancing flow. As such, future research may examine how variations in challenge-skill balance may contribute to outcome expectancies and the extent to which this may mediate changes in flow.

An additional psychological variable that may have similar benefits for attention is positive affect. Flow has been described as a positive experience right from the early work by Csikszentmihalyi (1975), but more recent findings using facial EMG have also shown increased positive affect during flow (de Manzano et al., 2010). Positive emotionality has been ascribed a variety of favorable effects, which include attentional improvements, including enhanced working memory (Ashby, Valentin & Turken, 2002), executive attention (Ashby & Isen, 1999) and the ability to screen out distractors (Compton et al., 2004). Interestingly, positive affect may also ameliorate feelings of pain or difficulty (Kahneman, 2011; Zautra et al., 2005) so could also contribute to the perceived effortlessness of flow. As such, both positive affect and outcome expectancies may be promising psychological constructs for future flow research.

6.1.2.5 Role of experimental manipulation

Developing an experimental approach to flow research in sport was outlined as an overarching aim of this thesis, in order to be able to investigate the attentional mechanisms. Experimental approaches have been used in gaming research (Keller & Bless, 2008; Keller et al., 2011) but have not been adopted in the sporting literature, possibly due to the difficulties of manipulating a fleeting experience in a dynamic environment (Moller, Meier & Wall, 2010). Based on Csikszentmihalyi's (1990) outline of challenge-skill balance, clear goals and unambiguous feedback as crucial precursors to flow, all studies were designed to provide these key elements. Csikszentmihalyi and Nakamura (2014) note that sports and games provide inherent goal and feedback structures. In line with previous research, Chapters 2, 3 and 4 based a manipulation on the challenge-skill balance. As a test of the attentional findings from these studies, Chapter 5 adopted an attentional focus manipulation to examine subsequent effects on flow. Overall there was mixed success, but the results suggest that this type of approach in a sporting setting is viable, and important for developing an understanding of mechanisms.

Chapters 2 (experiment 1b) and 3 aimed to manipulate the *perceived* challenge-skill balance in a basketball/netball task by giving challenging and varying goals for participants. In chapter 2, the challenge-skill balance was created through participants attempting to beat their own score. In chapter 3 it was created by providing goals that ranged from easy to hard, such that an optimal balance could be found in-between. In both studies clear goals were provided through targets to aim for, and feedback came from success/failure on both individual shots and in relation to goal achievement. There was found to be no effect of the manipulation in either experiment, which may have been due to the overarching goal of scoring a basket taking precedence over the variety of targets to achieve (Locke, Shaw, Saari & Latham, 1981). Participants' perception of challenge-skill balance may have depended more on their general perceived ability in the task, rather than whether they were reaching the set targets.

An additional consideration, given recent findings, is how open versus fixed goals may affect flow. Work by Swann and colleagues suggests that open goals may be more conducive to flow (Schweickle, Groves, Vella & Swann, 2017), while fixed goals may promote 'clutch' states. In their model of flow and clutch states Swann et al. (2017) propose that providing open 'do your best' goals promotes flow, while providing fixed outcome focused goals promotes a clutch state. These predictions were tested by Schweickle et al. (2017), who found that prescribing participants open goals in a letter/number identification task lead to more flow like experiences, while fixed goals lead to 'clutch' experiences. However, the novel measure used by Schweickle et al. to infer 'clutch' mainly reflects that participants exerted more deliberate effort. Also, one of the items used asked whether participants were focused on achieving an outcome, creating a degree of circularity in the conclusions, given the manipulation. The traditional definition of clutch describes it as maintenance of performance under pressure (Otten, 2009), but there is no indication that participants in this study were under any particular pressure. As such these findings may only indicate that specific goals lead to greater conscious effort, rather than 'clutch' in the traditional sense. Increased effort when provided with specific goals is in line with the predictions of goal-setting theory (Locke & Latham, 2013), particularly as Schweickle et al. still found fixed goals to lead to best performance. Therefore, even though the goal manipulations used in study 1b and 2 reflect fixed goals, there is little evidence to suggest that this will be detrimental to flow. On the contrary, as this thesis has highlighted the role of attentional effort in flow, fixed goals that increase effort and performance, as found by Schwieckle et al. (2017) and consistent with goal-setting theory (Locke & Latham, 2013), may still be optimal for flow.

Given the limited effect of goals on flow found in chapters 2 and 3, chapter 4 adopted the more typical approach of changing the task demands, which has shown previous success (Engeser & Rheinberg, 2008; Keller & Bless, 2008). Here it was also effective in in creating differences in flow experience across three levels. In this study, clear goals were provided by the structure of the task, trying to complete the race in the shortest time possible and clear feedback was provided by lap times and the constant feedback from control and speed of the car. The drawback of this approach is the confounding effect of task differences when making group comparisons, particularly for measures like performance. Additionally this approach within the literature has only been able to address half of the challenge-skill balance, as skills cannot be controlled. One approach may be to examine flow over time as skills in a novel task are acquired, alongside fluctuations in task difficulty.

Chapter 5 attempted an alternative approach, with the experimental manipulation providing a test of theory by directing attentional focus. There was found to be a significant increase in flow experience under external focus conditions, indicating a causal effect of attention on flow. The success of this approach highlights that in order to develop flow theory, especially in the sporting domain, controlling factors that are proposed as key antecedents allows a strong test of predictions. In this way a greater understanding of how to achieve flow can be gained. Similar approaches can be used to test the influence of self-efficacy, arousal, positive affect etc. This will also allow practical applications for flow interventions to be developed.

Overall, there was found to be no effect of providing a range of goals, perhaps because they had a limited effect on perceived challenge-skill balance. Future studies may wish to focus on the manipulation of task demands that was successful in chapter 4. Alternatively, the potential for influencing flow through feedback is yet to be examined. Providing non-contingent feedback holds potential for examining whether flow can be experienced when performance is poor. However, Brewer et al. (1991) demonstrated that false feedback can bias the retrospective report of flow, showing that disentangling the real experience from the self-report may prove challenging.

6.1.3 Issues, implications and future research

6.1.3.1 Limitations of the thesis

A particular limitation of the thesis, and the literature in general, is the reliance on self-report instruments. Aside from issues relating to response bias and retrospective inaccuracies is the more philosophical issue of turning complex human experience into scores on a questionnaire, which Csikszentmihalyi (1992, p.183) warns may be mistaking 'the reflection for the reality'. This is a form of reductionism, but one that is required to identify when flow has occurred. Reductionism is the view that human behaviour can be explained by breaking it down into constituent parts, which reflects a general, approach of this thesis in trying to identify cognitive mechanisms responsible for flow. When measuring flow, the aim was to identify the extent to which it occurred in various tasks, rather than to describe what the experience was actually like. Some researchers (e.g. Csikszentmihalyi, 1992; Jackson 1992) warn against examining flow too closely, but as an experience made up of normal cognitive processes, these processes can be examined separately. Therefore the reductionist approach is necessary for a mechanistic understanding of flow; the crucial issue is to recognise the approach for what it is, an imperfect way of measuring something complex in a simple way. Correspondingly, more holistic approaches, which take account of the nature of the personal experience are also required within flow research to understand the state as a whole.

A parallel issue relates to whether we can know that a particular score on a questionnaire means flow has occurred. This is clearly not possible, and given the experimental setting, full-blown flow experiences may be unlikely, but in line with the general approach of the thesis in viewing flow as a combination of normal cognitive processes it is not a binary, all or nothing experience. Processes like concentration, self-awareness, effort, etc., can all occur to a greater or lesser degree and this can be reflected in higher or lower scores on a self-report scale. This is in line with Csikszentmihalyi's descriptions of 'micro' and 'macro' flow. Following this, it is the relative changes in self-report scores as a result of experimental control that is crucial, rather than trying to identify if some arbitrary marker of flow was reached. Again, it is key to acknowledge the assumptions of the approach being used.

A second issue is the difficulty experienced with the experimental manipulation in Chapters 2 and 3. The intention was to compare groups, in order to make inferences regarding causality. As there were no flow differences between groups, a correlational approach was used to assess how flow was related to quiet eye and performance variables. These experiments aimed to avoid this type of approach, but this was unavoidable in Chapters 2 and 3. As a result of the effective challenge manipulation in Chapter 4, it was possible to draw firmer conclusions from the findings.

6.1.3.2 Applied implications

The principal application that can be derived from this series of studies is the potential efficacy of attentional focusing and training techniques for achieving flow. As it was found that attention control may be improved during flow (Chapters 3 and 4), and that appropriate attentional focus leads to increased flow (Chapter 5), a range of techniques for promoting optimal focus in sporting tasks are likely to be of benefit for enhancing flow experience. That appropriate attentional focus and development of attentional skills is likely to benefit performance is hardly a novel suggestion (Mann et al., 2007; Tang & Posner, 2009; Wulf, 2013), but these studies provide the first indication that existing attention techniques may also provide the best method for eliciting positive experiential states like flow.

Good attention can be promoted in two main ways; in-game techniques for focusing or longer-term training for lasting improvements. Focusing techniques might include instructional self-talk which can improve task focus and reduce intrusive thoughts (Tod, Hardy & Oliver, 2011). Similarly pre-performance routines are suggested to induce a particular attentional focus, reduce distractors and trigger automated movement patterns (Cotterill, 2010), so may have a facilitative effect. Alternatively, given the results of Chapter 5, adopting an appropriate attentional focus is likely to have benefits for flow. As an external focus of attention has been found to promote a task focus and a reduction in disruptive self-awareness (Wulf, 2013), cues to induce a focus on movement effects may provide a particularly useful strategy for increasing flow.

Alternatively, longer-term training of attention abilities may allow a more general increase in flow across multiple tasks. Previous research has supported some benefit of mindfulness practice for enhancing flow (Aherne, Moran & Lonsdale, 2011; Kaufman, Glass & Arnkoff, 2009; De Petrillo et al., 2009), although no performance improvements were found (De Petrillo et al., 2009). Dietrich (2003) describes mindfulness and flow as similar states of reduced frontal function, however mindfulness often emphasises bodily awareness (Kabat-Zinn, 1994) which is somewhat at odds with the reduction in self-awareness found in flow (Dietrich, 2003). As such it may not be optimal for increasing flow.

Given the results of Chapter 3 and 4, programmes that directly target attention control ability are likely to be beneficial. For instance Ducroq et al. (2017) found that training in a visual search task (identifying yellow tennis balls amongst distractors) improved inhibitory control under elevated pressure. There are a variety of computerised attention control tasks (e.g. n-back and dual-tasks) that target functions like working memory and selective attention but far transfer to new tasks seems to be limited (Tang & Posner, 2009; Melby-Lervåg & Hulme, 2016). As training may indeed need to be task specific, and given the relationship between flow and QE in Chapter 3, methods that promote goal-directed gaze control like Quiet Eye Training (QET) may hold the greatest promise. QET provides performers with instructions to lengthen/maintain the QE during an aiming task, enhancing performance and facilitating top-down control, particularly under anxiety (Vine, Moore & Wilson, 2011; Vine & Wilson, 2011). As such, learning to control visual attention may be an effective intervention for increasing attention control and flow.

These approaches all suggest that to achieve effortless attention (Bruya, 2010) a prior effortful investment may be required. In particular, both attention control training tasks and QET require effortful, deliberate focusing of attention, but based on the findings of this thesis, this may become effortless when the task provides an optimal challenge and individuals become immersed in the task. Much as learning a motor skill progresses from being effortful to being effortless (Lee, Swinnen, & Serrien, 1994), finding flow in a task may progress from an initial effortful investment.

6.1.3.3 Future research

As discussed previously, the reliance on self-report measures presents significant challenges for flow research, but as flow is defined by the phenomenological experience this type of measurement cannot be neglected. Therefore the key method for advancing flow research must include a combination of subjective and objective measures, as was the approach of this thesis. If direct measurement of flow becomes sufficiently advanced it may become possible to identify flow without recourse to self-report, which would provide the decisive benefit of being able to identify flow 'online' without stopping to ask about the experience. De Manzano and colleagues (2010) discuss flow as a state of positive valence and high arousal, finding flow to relate to cardiovascular, respiratory and facial EMG measures. As a result they suggest that flow could be diagnosed online as a combination of sympathetic autonomic activity, deep breathing and activation of facial muscles indicative of positive affect, but given the many to one mappings of psychological states to physiological responses, flow research may need to develop further before this is reliable (Cacioppo & Tassinary, 1990).

Of the research discussed in this thesis, recent neuroimaging studies have been particularly important in advancing our understanding of attentional mechanisms. Studies by Ulrich et al. (2014, 2016) using fMRI and fMRPI have utilised the traditional paradigm of manipulating the challenge-skill balance in arithmetic tasks, providing evidence of increased activity in higher attentional networks and reduced self-referential activity under optimal challenge. The benefits of this approach are clear, in that cognitive mechanisms can be investigated whilst participants are engaged in a flow activity, although the ecological validity of the tasks used is necessarily limited. A useful intermediary approach may be to use more representative tasks like movement controlled and immersive gaming with direct, but less intrusive measures of attention like eye-tracking and EEG (Cheron, 2016). These types of direct measurement techniques are required to answer theoretical questions, but should nonetheless be considered in the light of qualitative approaches that explore the crucial role of subjective experience in flow (Kimiecik & Stein, 1992; Csikszentmihalyi, 1992).

In terms of specific research questions that need addressing, a natural next step is to investigate how attentional interventions and training can be used to enhance flow. The proposition that attention is the key mechanism in flow requires further validation, but attentional manipulations can provide this test of theory. Various attentional training methodologies can be combined with the Experience Sampling Method (Csikszentmihalyi & Larson, 2014) to investigate whether improved attention control abilities enable more frequent flow experience in all manner of everyday tasks. Meanwhile, sport specific gaze training (QET) can be usefully investigated for achieving flow in a more performance focused environment.

6.1.4 Final thoughts

A notable absence in the flow literature is the customary academic debate over definitions. There is almost ubiquitous adherence to the original descriptions and dimensions of flow proposed by Csikszentmihalyi's (1975; 1990) early work. Given the complex nature of flow, this points to the remarkable job that was done in outlining the key features of the experience, but also raises concerns as to whether a widespread loyalty to one research paradigm could have constrained the literature (Kuhn, 1974).

There is really no flow *definition,* rather the state is described by its experiential components (Stoll, 2016), which perhaps suggests that we are still unsure what the key feature is. Csikszentmihalyi (1992, p.183) warns against 'breaking the spirit' of flow by defining it too precisely, but to advance a mechanistic understanding of flow this may be unavoidable. Recent work by Swann and colleagues (Swann et al., 2016; Swann, Crust & Vella, 2017) has outlined flow as a state of 'letting it happen', in line with research by Dietrich and colleagues (Dietrich, 2006; Dietrich & Stoll, 2010; Stoll, 2016) which focuses on automaticity and hypofrontality. In contrast, this thesis has suggested that in fact effortful processes are crucial, but individuals are unaware of the effortful, deliberate attention that is required by the task. An alternative approach is to develop more detailed definitions and sub-types of flow, allowing for these conceptual differences through divergent definitions. For instance, the work of Stoll (2016) on the runner's high and flow may highlight a particular sub-type where little executive activity is required and automaticity is indeed the key feature. On the other hand, flow experience at work or in highly complex computer games requiring selective attention, response inhibition etc., suggests that flow can be experienced when demands on higher attention abilities are vast. Therefore, a more nuanced approach to defining flow may be needed in order that researchers are not proposing theories that are apparently contradictory but based on differing definitions.

6.2 Final Conclusions

This thesis aimed to examine the role of attention in flow through experimental methods and direct measures of gaze behaviour. In sporting and gaming tasks flow was linked to changes in visual attention, with findings suggesting optimal attention control to be a possible proximal mechanism for flow experience. Clearly additional research is required to develop the methods used here, and to validate attentional changes as a mechanism for flow.

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8. Appendices

8.1 Example Informed Consent Form

Study: The role of attentional control in flow states.
Principal Investigator: David Harris
Researcher:
Organisation: The University of Exeter
Version: #1 xxxx:
Participant Identification Number:

Informed consent form for participants

1. I confirm that I have read and understand the information sheet version #1 dated xxxx, for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐

3. I understand that any information given by me may be used in future reports, articles or presentations by the research team. ☐

4. I understand that my name will not appear in any reports, articles or presentations. ☐

5. I understand that I will be asked to xxxx. ☐

6. I understand that I will be asked to wear xxxx. ☐

7. I understand that I will be required to answer a series of questionnaires about my experience during the experiment. ☐

8. I give consent for my performance data to be kept for future studies. ☐

9. I agree to take part in the above study. ☐

______________________	________________	________________
Name of Participant	Date	Signature
David Harris______________	________________	________________
Researcher	Date	Signature

8.2 Attention Control Scale (Derryberry & Reed, 2002)

ACS

Here are some different ways that people can feel about working and concentrating. Please indicate how strongly each statement applies to you. (Please circle)

1=Almost never
2=Sometimes
3=Often
4=Always

1.	It's very hard for me to concentrate on a difficult task when there are noises around.	1	2	3	4
2.	When I need to concentrate and solve a problem, I have trouble focusing my attention.	1	2	3	4
3.	When I am working hard on something, I still get distracted by events around me.	1	2	3	4
4.	My concentration is good even if there is music in the room around me.	1	2	3	4
5.	When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.	1	2	3	4
6.	When I am reading or studying, I am easily distracted if there are people talking in the same room.	1	2	3	4
7.	When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.	1	2	3	4
8.	I have a hard time concentrating when I'm excited about something.	1	2	3	4
9.	When concentrating I ignore feelings of hunger or thirst.	1	2	3	4
10.	I can quickly switch from one task to another.	1	2	3	4
11.	It takes me a while to get really involved in a new task.	1	2	3	4
12.	It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures.	1	2	3	4
13.	I can become interested in a new topic very quickly when I need to.	1	2	3	4

14. It is easy for me to read or write while I'm also talking on the phone.	1	2	3	4
15. I have trouble carrying on two conversations at once.	1	2	3	4
16. I have a hard time coming up with new ideas quickly.	1	2	3	4
17. After being interrupted or distracted, I can easily shift my attention back to what I was doing before.	1	2	3	4
18. When a distracting thought comes to mind, it is easy for me to shift my attention away from it.	1	2	3	4
19. It is easy for me to alternate between two different tasks.	1	2	3	4
20. It is hard for me to break from one way of thinking about something and look at it from another point of view.	1	2	3	4

8.3 Mindful Attention Awareness Scale

Name; ____________________ Email; _________________

Day-to-Day Experiences

Instructions: Below is a collection of statements about your everyday experience. Using the 1-6 scale below, please indicate how frequently or infrequently you currently have each experience. Please answer according to what really reflects your experience rather than what you think your experience should be. Please treat each item separately from every other item.

1	2	3	4	5	6
Almost Always	Very Frequently	Somewhat Frequently	Somewhat Infrequently	Very Infrequently	Almost Never

I could be experiencing some emotion and not be conscious of it until some time later.	1	2	3	4	5	6
I break or spill things because of carelessness, not paying attention, or thinking of something else.	1	2	3	4	5	6
I find it difficult to stay focused on what's happening in the present.	1	2	3	4	5	6
I tend to walk quickly to get where I'm going without paying attention to what I experience along the way.	1	2	3	4	5	6
I tend not to notice feelings of physical tension or discomfort until they really grab my attention.	1	2	3	4	5	6
I forget a person's name almost as soon as I've been told it for the first time.	1	2	3	4	5	6
It seems I am "running on automatic," without much awareness of what I'm doing.	1	2	3	4	5	6

1 2 3 4 5 6

Statement	Almost Always	Very Frequently	Somewhat Frequently	Somewhat Infrequently	Very Infrequently	Almost Never
I rush through activities without being really attentive to them.	1	2	3	4	5	6
I get so focused on the goal I want to achieve that I lose touch with what I'm doing right now to get there.	1	2	3	4	5	6
I do jobs or tasks automatically, without being aware of what I'm doing.	1	2	3	4	5	6
I find myself listening to someone with one ear, doing something else at the same time.	1	2	3	4	5	6
I drive places on 'automatic pilot' and then wonder why I went there. [leave blank if you do not drive]	1	2	3	4	5	6
I find myself preoccupied with the future or the past.	1	2	3	4	5	6
I find myself doing things without paying attention.	1	2	3	4	5	6
I snack without being aware that I'm eating.	1	2	3	4	5	6

8.4 Flow State Scale-2 (Jackson and Eklund, 2002)

Please answer the following questions in relation to your experience in the event or activity you have just completed. These questions relate to the thoughts and feelings you may have experienced while taking part. There are no right or wrong answers. Think about how you felt **DURING THE LAST 5 MINUTES** and answer the questions using the rating scale below.

For each question circle the number that best matches your experience.

Rating Scale:

Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
1	**2**	**3**	**4**	**5**

1. I was challenged, but I believed my skills would allow me to meet the challenge.
   1 2 3 4 5

2. I made the correct movements without thinking about trying to do so.
   1 2 3 4 5

3. I knew clearly what I wanted to do
   1 2 3 4 5

4. It was really clear to me how my performance was going.
   1 2 3 4 5

5. My attention was focused entirely on what I was doing.
   1 2 3 4 5

6. I had a sense of control over what I was doing.
   1 2 3 4 5

7. I was not concerned with what others may have been thinking of me.
   1 2 3 4 5

8. Time seemed to alter (either slowed down or speeded up).
   1 2 3 4 5

9. I really enjoyed the experience.
   1 2 3 4 5

10. My abilities matched the high challenge of the situation.
    1 2 3 4 5

11. Things just seemed to be happening automatically.
    1 2 3 4 5

For each question circle the number that best matches your experience.

Rating Scale:

Strongly Disagree / Disagree / Neither agree nor disagree / Agree / Strongly Agree

1 2 3 4 5

12. I had a strong sense of what I wanted to do.
1 2 3 4 5

13. I was aware of how well I was performing.
1 2 3 4 5

14. It was no effort to keep my mind on what was happening.
1 2 3 4 5

15. I felt like I could control what I was doing.
1 2 3 4 5

16. I was not concerned with how others may have been evaluating me.
1 2 3 4 5

17. The way time passed seemed to be different from normal.
1 2 3 4 5

18. I loved the feeling of the performance and want to capture it again.
1 2 3 4 5

19. I felt I was competent enough to meet the high demands of the situation.
1 2 3 4 5

20. I performed automatically, without thinking too much.
1 2 3 4 5

21. I knew what I wanted to achieve.
1 2 3 4 5

22. I had a good idea while I was performing about how well I was doing.
1 2 3 4 5

23. I had total concentration.
1 2 3 4 5

24. I had a feeling of total control.
1 2 3 4 5

25. I was not concerned with how I was presenting myself.
1 2 3 4 5

For each question circle the number that best matches your experience. Rating Scale: Strongly Disagree / Disagree / Neither agree nor disagree / Agree / Strongly Agree **1 2 3 4 5**

26. It felt like time went by quickly.
1 2 3 4 5

27. The experience left me feeling great.
1 2 3 4 5

28. The challenge and my skills were at an equally high level.
1 2 3 4 5

29. I did things spontaneously and automatically without having to think.
1 2 3 4 5

30. My goals were clearly defined.
1 2 3 4 5

31. I could tell by the way I was performing how well I was doing.
1 2 3 4 5

32. I was completely focused on the task at hand.
1 2 3 4 5

33. I felt in total control of my body.
1 2 3 4 5

34. I was not worried about what others may have been thinking of me.
1 2 3 4 5

35. I lost my normal awareness of time.
1 2 3 4 5

36. I found the experience extremely rewarding.
1 2 3 4 5

8.5 Flow short scale (Rheinberg, Vollmeyer & Engeser, 2003)

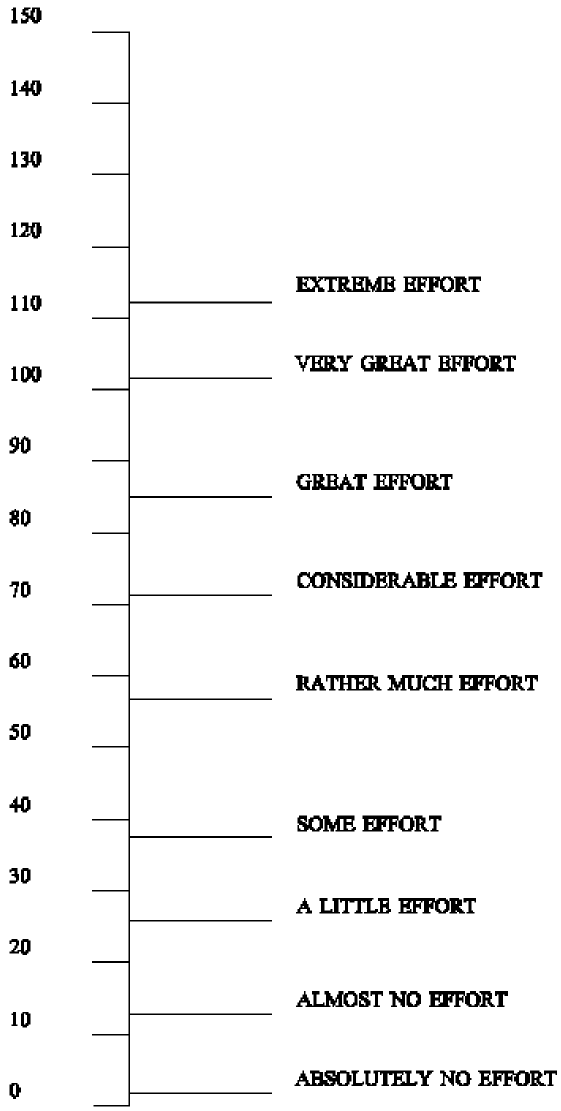
With regards to the activity you have just completed, to what extent do these statements describe your experience?

	Very much			Partly			Not at all
1. I feel just the right amount of challenge	1	2	3	4	5	6	7
2. My thoughts/activities run fluidly and smoothly	1	2	3	4	5	6	7
3. I do not notice time passing	1	2	3	4	5	6	7
4. I have no difficulty concentrating	1	2	3	4	5	6	7
5. My mind is completely clear	1	2	3	4	5	6	7
6. I am totally absorbed in what I am doing	1	2	3	4	5	6	7
7. The right thoughts/movements occur of their own accord	1	2	3	4	5	6	7
8. I know what I have to do each step of the way	1	2	3	4	5	6	7
9. I feel that I have everything under control	1	2	3	4	5	6	7
10. I am completely lost in thought	1	2	3	4	5	6	7

8.6 Rating scale mental effort (Zijlstra, 1993)

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished



8.6 Example information sheet for participants (from Chapter 5)

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Web www.ex.ac.uk/sshs

Study: The role of attentional control in flow states
Principal Investigator: David Harris
Organisation: The University of Exeter
Participant Identification Number:
Version: #1. 27.01.17

Participant Information sheet

Thank you for your interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you choose not to participate there will be no disadvantage to you of any kind, thank you for considering participation.

What is the aim of the project?

We aim to assess individuals' eye movements during a computer based driving game.

What types of participants are needed?

The participants used will consist of undergraduate students from the University of Exeter.

What will participants be asked to do?

Should you agree to take part in this project, you will be asked to come into the laboratory on one occasion for roughly 50 minutes, and play a driving simulation game whilst wearing a pair of eye tracking glasses.

Eye tracking glasses are a larger, plastic version of reading glasses, with a small camera attached to record movement of the eye, which is designed to be light and wearable during motion.

You will also be asked to complete some questionnaires about your experience.

Can participants change their mind and withdraw from the project?

You may withdraw participation at any time without any disadvantage to yourself.

What data or information will be collected and what use will be made of it?

We will collect data of performance scores based on the driving task and your steering movements, as well as eye-tracking data. There will also be some questionnaire data collected during driving.

All information obtained will be stored on computer in coded form and individual results will remain confidential. Results of this study may be published but any data included will in no way be linked to any specific person.

Any questions?

If you have any questions about this project, either now or in the future, please feel free to contact:

David Harris

Email: dh386@exeter.ac.uk

or

Dr Mark Wilson

Email: Mark.Wilson@exeter.ac.uk

This project has been reviewed and approved by the Sport and Health Sciences Ethics Committee, University of Exeter.