The effects of mindfulness training on indices of cognition, stress and immune function in team-sport athletes

Luke MacDonald, BClinExSci Hons
Griffith University
Queensland Academy of Sport

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Declaration

I declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material that has been accepted or submitted to any other institution for an academic award or previously published or written by another person, except where due reference has been made.

Luke MacDonald                                                     Date: 15/08/16
Preface

Human potential is a fascinating concept. The saying, ‘you can achieve anything if you set your mind to it,’ has certainly passed through my ears on many occasion. I look at some of the greatest athletes in recent history: Michael Phelps, Kelly Slater, Roger Federer, Kobe Bryant in awe of what they have achieved and wonder: what makes them so great? How have they managed to achieve what they have? Undoubtedly, incredible natural talent, physical stature, and mental attributes such as determination, perseverance and self-belief contribute to their success. But I’ve always believed there’s more to it; they all possess the ability to achieve a superlative mental focus during competition. But how do they put their entire focus on the task at hand in such highly stressful and physically demanding situations? Could it be that they have the ability to achieve a heightened state of mindfulness?

In 2014, the Seattle Seahawks achieved the unthinkable and won the 48th Super Bowl; the 2014 NFL championship. Head coach, Pete Carroll, attributed their success to the help of Michael Gervais, one of the world’s leading performance psychologists. In an interview following the Super Bowl win, Gervais was asked, ‘Obviously your end goal was winning, but what were your strategies with the Seahawks?’ At that point, Gervais’s tone of voice changed, almost concerned, and responded: ‘See, we don’t talk about winning. The goal for us is to be fully engaged at a really rich level to figure out and explore what is possible in your own life. And, if you get enough people resonating in that space, winning just happens as a result of this.’ Michael Gervais brought mindfulness training to the Seattle Seahawks and it has since become an integral part of their training regime.
Phil Jackson is the most decorated NBA coach in history; winning six championships with the Chicago Bulls, during the ‘Michael Jordan era’ and another five with the L.A Lakers during the ‘Kobe Bryant era.’ When Jackson became the head coach of the Chicago Bulls in 1989, he brought with him what he calls a ‘One Breath, One Mind’ approach: mindfulness. In an interview with Oprah in 2013, he explained this approach, ‘We needed to build our mental strength. We needed to build our mental strength so we could focus, obtain one-pointed attention and be in concert with one another in times of need. When you come off the court or you’ve had a bad call, things may be going wrong. You sit on the bench, you take a breath and you reset yourself. You do that through mindfulness; come back in and collect yourself.’

Mindfulness training (MT) has been practiced for thousands of years in Eastern and Buddhist traditions. In the latter half of the last century, MT made its way into Western society in the mode of clinical therapies for treating psychological and mood disorders. In addition, the positive health benefits of MT are now well established in clinical research. With this is in mind, sports psychologists and coaches have investigated whether MT could hold a valuable place in sport. Nowadays, MT is commonly used in elite sports such as the NBA, NFL, and the AFL. In addition, this has led to a small, but growing body of research surrounding MT and sport. However, additional research is required to understand how MT may improve objective measures that contribute to sports performance.

This thesis is presented in seven chapters. The first chapter contains an overview of the literature pertaining to MT, both in clinical and sporting disciplines, as well as including literature to provide an understanding and justification as to why I chose my direction with this thesis. Chapters two through to six are individual experimental studies, written in manuscript format that have been submitted for peer-review or accepted for publication. The
final chapter contains a general discussion, the limitations of my experiments as well as the practical applications that have come from this thesis. Finally, future considerations have also been deliberated followed by a conclusion.
Experimental Chapters:

Chapter 2: ‘Indices of Cognitive Function measured in Rugby Union Players using a Computer-Based Test Battery’

Chapter 3: ‘The effects of brief mindfulness meditation on indices of cognitive function in trained rugby union players’

Chapter 4: ‘The effects of mindfulness meditation training on indices of cognitive function in rugby union players’

Chapter 5: ‘Reliability of salivary cortisol and Immunoglobulin-A measurements from the IPRO® before and after sprint cycling exercise’

Chapter 6: ‘Mindfulness training attenuates the increase in salivary cortisol concentration associated with competition in highly-trained wheelchair basketball players’
List of peer-reviewed publications


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It is often said that completing a PhD can be a long and lonely journey. And yes, at times it was lonely and felt like it was never going to end. I’ve also often heard people say that a PhD is a great individual achievement. But that would mean I have accomplished this all on my own. I strongly disagree. Throughout the last three and a half years I have had so much incredible support and guidance from such wonderful people, on both a personal and professional level, that have made this journey not so lonely and, at times, wonderful for me.

Firstly, I would like to thank my primary supervisor, Clare Minahan. Clare, you taught me that the motivation for this research had to solely come from within myself. It took some time for me to realise this. But when I did, it all made sense, and I thank you for that. There were times when I was lost along the way and you kept me on track; just enough for me to still make the mistakes that I needed to make in order for me to learn from them, and continue to move forward. I have learnt so much from you; your intelligence, incredible writing skills, scientific rigor and attention to detail have been invaluable. You were such an immense support during my postgraduate studies and I will be forever grateful for this. It was great sharing an office with you; I felt more motivated and focused than I had ever been while still being able to chat about sport and current affairs. You’ve been a great mentor and a true friend. It’s the end of an era, but I do hope that the future will allow for us to work together again. Thank you, Clare.

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were stressful, helping me with my research and just being good mates. You are both inspirations in your own right, and I would not be at this point now without you. Best of luck with your future endeavours and I am sure great things lie ahead for the both of you.

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Summary

Mindfulness training (MT) has gained great research attention in the areas of psychology and cognitive neuroscience with demonstrated health benefits in both clinical and healthy populations. Moreover, there is a growing interest in the sporting world in understanding the efficacy of MT to enhance athletic performance. The primary aim of this thesis was to investigate whether mindfulness training (MT) can improve cognition and reduce stress in team-sport athletes.

Experiment 1 was designed to investigate the intra and inter-day reliability of the computer-based test battery in team-sport athletes. Male rugby union players performed repeated trials on the same day and 24 h later. The test battery comprised of four cognitive tests assessing the cognitive domains of executive function (Groton Maze Learning Task, GMLT), psychomotor function (Detection Task, DET), vigilance (Identification Task, IDN), visual learning and memory (One Card Learning Task, OCL). We demonstrated ‘good’ to ‘excellent’ intra- and inter-day reliability for performance variables of the DET, the IDN and the OCL. However, the reliability of the GMLT was questionable and so results were interpreted with caution in Experiment 2.

Experiment 2 was designed to investigate whether a brief mindfulness meditation session could alter performance of the cognitive test battery. Male rugby union players performed two trials of the cognitive test battery separated by either a 20-min mindfulness meditation session (Mindful group) or quiet rest (Control group). We found that any improvements or decrements in cognitive performance observed in the Mindful group were also seen in the Control group indicating that the 20-min mindfulness meditation session had no effect on cognitive performance. It is possible that the mindfulness meditation session was not long
enough to elicit a change in performance of the cognitive test battery. In addition, a single session of mindfulness meditation may not be enough to elicit a change in cognition. Therefore mindfulness meditation training (i.e., MT) may be more sufficient to elicit an acute- as well as a chronic effect on cognitive performance.

The purpose of experiment three was to determine if 4 wk of MT could provoke a chronic effect on cognitive performance in a team of trained rugby union players. The Mindful group performed three, 20-min mindfulness meditation sessions each week during the intervention. Cognitive performance was assessed at baseline (0 wk), mid-intervention (2 wk), and follow-up (4 wk). There was no mean improvement in any of the cognitive tests throughout the 4 wk of MT ($P > 0.05$). It is possible that the dose of mindfulness meditation (three, 20-min sessions each week for four weeks) was not substantial enough to evoke an improvement in cognitive function in the rugby union players. It is also possible that the cognitive test battery was not sensitive enough to highlight potential changes in cognitive function evoked by MT. Furthermore, perhaps the positive influences of MT only manifest on performance determinants other than cognitive function.

Considering the findings of experiment two and three, further research was directed towards other factors that may be positively influenced by MT. Previous research has highlighted the effects of MT on stress and immune function in both and clinical and healthy populations. Specifically, studies have shown that MT can improve concentrations of salivary cortisol (sCort) and secretory-Immunoglobulin-A (sIgA). Therefore, if MT can reduce sCort and increase sIgA in athletes, this would be beneficial in reducing the increase in stress and improving mucosal immune function during competition.
We wanted to incorporate a new point of care salivary analysis system, the Individual Profiling (IPRO), to determine sCort and sIgA. However, there was limited data available regarding the inter-day reliability of the IPRO to determine sCort and sIgA as well as its ability to detect a change in sIgA and sCort in response to an intervention (i.e., exercise). Therefore, Experiment 4 evaluated the inter-day reliability of the IPRO method for determining resting and post-exercise sCort and rate of sIgA secretion. Healthy active males performed two experimental trials, separated by 7 d, comprising saliva sampling before and after completion of two, 30-s Wingate Anaerobic Tests. We demonstrated the IPRO is a reliable method for determining sCort concentration and rate of sIgA secretion at rest and after sprint-cycling exercise.

Experiment 5 evaluated the effect of 8 wk of MT on sCort and rate of s-IgA secretion in wheelchair-basketball players while they completed a 7-wk competition period. The Mindful group completed 8 wk of MT while the Control group completed regular training and competition. sCort and rate of sIgA secretion were measured at baseline and 2-wk intervals during the intervention period. sCort increased in the Control group and remained elevated during the competition period before returning to a concentration similar to baseline following completion of competition. sCort briefly increased in the Mindful group but returned to concentrations no different to baseline after only 2 weeks of competition for the rest of the intervention period. In addition, any changes observed in rate of sIgA secretion were not different between groups. We concluded that 8 wk of MT attenuated the chronic increase in resting sCort in the Mindful group that was observed in the Control group during the competition period.
The findings of this thesis provide new evidence surrounding the effects of MT on cognition and stress in athletes. This thesis contributes novel information with important implications for sports scientists and coaches who wish to implement MT in their athletes for the purpose of improving cognition or managing stress during competition. In addition, this work has contributed on a methodological level by establishing reliability in both a neurocognitive test battery and a new point of care salivary analysis system.
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CHAPTER 1: Overview
1.1 Introduction

Elite team-sport is performed in dynamic environments, under conditions of stress, where human achievement is constantly being challenged and extended. On the field, an athlete’s performance is determined by both their physical and mental ability. Physical attributes may include strength, power, endurance and the ability to perform intermittent, high-intensity efforts; whereas, mental skills such as self-motivation, mental imagery and positive self-talk are necessary for successful team-sport performance. In addition, Buszard, Farrow, and Kemp (2013) propose that team-sport athletes must possess the ability to: i. Attend to important environmental information, ii. Recognise and recall patterns of play, and iii. Make correct decisions during a game or match (Buszard et al., 2013; Roca, Ford, McRobert, & Williams, 2013). Thus, although physical and mental skills are essential, it could be suggested that cognitive function in the areas of attention, working memory and executive function play an integral role in athletic performance.

Interestingly, recent evidence suggests that poor cognitive function is associated with subsequent non-contact injury incidence in athletes (Swanik, Covassim, Stearne, & Schatz, 2007). Deficits in basic cognitive function may compromise an athlete’s judgement, cause loss of coordination and place them at risk of injury. Therefore, it seems plausible to explore an intervention with the potential to increase basic cognitive function in athletes as it may help to reduce non-contact injury prevalence in team-sports.

In addition to on-field demands, team-sport athletes are required to travel and perform at their best, while continuing to train at a high intensity. Consequently, athletes are exposed to increasing amounts of physical and psychological stress (Fernandez-Fernandez et al., 2015).
If recovery strategies and psychological interventions are not sufficient to overcome stress and maintain both physical and mental well-being, athletes may become susceptible to illness and/or injury (Kellman, 2010; Kreher & Schwartz, 2012). Stress is commonly indexed by the steroid hormone cortisol and is considered important for preparation for competition as well as examining the response to a certain stressor (i.e., exercise). Nonetheless, chronic elevation of cortisol can lead to adverse physiological (Eichner, 1995; Kellmann, 2010) and cognitive consequences (Erickson, Drevets, & Schulkin, 2003), and has previously been associated with overtraining syndrome in athletes (Kellmann, 2010). Therefore, in addition to improving cognitive function, an intervention that has the potential to assist athletes with managing stress, as well as optimising immune function could be useful in helping to maintain physical well-being.

There is a growing emphasis on novel approaches to improving cognition and reducing stress such as yoga (Gothe, Pontifex, Hillman, & McAuley, 2013; Smith, Hancock, Blake-Mortimer, & Eckert, 2007) and meditation (Hodgins & Adair, 2010). The use mindfulness training (MT) and the associated positive health benefits have been well established (Grossman, Niemann, Schmidt, & Walach, 2004; Hölzel et al., 2011). Furthermore, athlete-focused MT interventions have been developed to increase sports performance (Baltzell & Akhtar, 2012; De Petrillo, Kaufman, Glass, & Arnkoff, 2009; Schwanhausser, 2009). Indeed, this research is valuable in understanding how MT can subjectively improve performance from an athlete’s internal perspective. Nevertheless, we wanted to examine whether MT may improve objective measures that contribute to athletic performance.

This overview will give a brief insight into MT and how it has made its way from Eastern tradition into Western cognitive and clinical psychology. In addition, neurological findings
will be discussed to better understand the mechanisms underlying MT and its practice; and how MT has been shown to improve cognitive function in clinical and healthy populations. Current literature pertaining to cognition in sport will also be discussed with respect to attention, working memory and decision-making. For the purpose of this thesis, stress and immune function will be determined by the measurement and analysis of cortisol and Immunglogulin-A (IgA, respectively). Therefore, a basic physiological understanding of both cortisol and IgA will be provided, their responses to exercise and the relevance of their measurement and analysis in the sporting world. This review will then explore the positive effects of MT on stress and immune function and how this may be transferrable to sport. Finally, although still in its infancy, the current state of knowledge about MT in sport will be deliberated, highlighting the gaps in the literature and the aims of this thesis.

1.2 Mindfulness training

The word ‘mindfulness’ is derived from the Pali word, ‘sati,’ originating from the Abhidamma (Kiyota, 1991) and more recently from the Vishuddimagga (Buddhaghosa, 1976). It is most commonly used to describe a particular type of meditation characterised by the monitoring of ‘present moment’ experiences, that are separated and considered as a possible development of concentrative or ‘focused attention’ meditations (Chiesa, Calati, & Serretti, 2011). The practise of mindfulness meditation stems from Buddhist philosophy and is a significant element in many Buddhist meditations such as Vipassana (Gunaratana & Gunaratana, 2011) and Zen (Kapleau, 1967). In more recent years, MT has been integrated into numerous clinically-focused, group-based meditation programs including Mindfulness Based Stress Reduction (MBSR), Mindfulness Based Cognitive Therapy (Williams, Teasdale, Segal, & Soulsby, 2000) and Integrative Body-Mind Training (Fan, Tang, Ma, & Posner, 2010). Additionally, Baer (2003) considered psychological interventions such as
Dialectical Behaviour Therapy (Linehan, 1993) and Acceptance and Commitment Therapy (Hayes, Strosahl, & Wilson, 1999) to be generally consistent with current theories of MT interventions. Although a novel therapy, there is sufficient current evidence that MT could have significant health benefits. These include reduced hypertension (Alberto Chiesa & Serretti, 2009), decreased anxiety and depression (Kim et al., 2009), reduced alcohol and substance abuse (Bowen et al., 2006), as well as benefits for cancer sufferers (Ledesma & Kumano, 2009).

A typical mindfulness meditation session can take many forms such as a group session lead by an instructor, an individual listening to a recording or simply meditating, at any time, without constraint or instruction. The individual may be sitting upright in a chair, or on the floor with their legs crossed. The individual’s back, neck, and head are aligned to the vertical, maintaining relaxed shoulders, their hands resting comfortably on their thighs facing upward, and with their eyes closed. The primary focus for the ‘naïve meditator’ is to direct their attention to the ‘present breath,’ along with other present happenings such as the feeling of their feet against the floor, the sound of the inhalation breath, or the feeling of the tension in their muscles (Kabat-Zinn, 2011). They may notice their mind wandering someplace else, whereby the individual may forget about the current breath. Distractions are to be accepted, at which point the individual calmly brings their attention back to the breath. This will deepen the concentration of the individual and will build inner strength by working with, and not against, the resistance of his or her own mind (Kabat-Zinn, 2011; Kabat-Zinn, 1994).

It has been suggested that MT includes three components that interact closely with one another to establish a process of heightened self-regulation comprising: attention control, emotion regulation, and self-awareness (Hölzel et al., 2011). According to Tang, Lu, Fan,
Yang, and Posner (2012) mindfulness training can be divided into three different stages of practice that involve different amounts of effort: 1. Effortful doing, 2. Effort to reduce mind-wandering, and 3. Effortless being. Tang, Holzel, and Posner (2015) have eloquently illustrated the processes to achieve self-regulation and three practices associated with MT (meditation) in Figure 1.1.

Figure 1.1. a. Mindfulness meditation enhances the three components of attention control, emotion regulation, and self-awareness to establish heightened self-regulation, and b. Three differential stages of mindfulness practice and the efforts associated. Source: Tang et al. (2015)
Interestingly, conceptualizations (Bishop et al., 2004; Brown & Ryan, 2003), as well as masters and instructors of MT and meditation (Gunaratana & Gunaratana, 2011; Kapleau, 1967; Williams et al., 2000), consistently point to the positive effects it has on the regulation of attention, memory, and other cognitive abilities. In more recent years, a number of studies have investigated changes in brain morphology and activation that are associated with the practice of, or that follow completion of a mindfulness training. Furthermore, researchers have been able to highlight, with objective measures, the positive effects MT has on stress and immune function. For the purpose of the present thesis, the neuroscientific findings of mindfulness research will be discussed with respect to the three components suggested by Hölzel, Lazar, et al. (2011). In addition, as this thesis has aimed to improve the fundamental aspects of cognition, current evidence surrounding the effects of MT on cognition will be deliberated with respect to attention, working memory and executive function. Finally, current research surrounding the effects of MT on physiological stress and immune function will also be discussed.

1.2.1 Neuroscientific findings

Previous functional and structural imaging studies have highlighted changes in the anterior cingulate cortex (ACC), posterior cingulate cortex (PCC), prefrontal cortex (PFC), insula, striatum (caudate and putamen), and amygdala associated with MT (Hölzel et al., 2011; Lutz, Slagter, Dunne, & Davidson, 2008; Tang et al., 2015). These areas are considered to be the core regions involved in attention and emotion regulation, as well as self-awareness and will be discussed in further detail.
Effects on attention regulation

Mindfulness researchers have evaluated the effects of MT on neuroplasticity in brain regions supporting attention regulation. The ACC is the most consistently reported brain region to have shown effects associated MT (Tang et al., 2010; Tang et al., 2009; Tang et al., 2012). The ACC is responsible for executive attention and control by detecting the presence of conflicts that develop from incompatible streams of information processing (Posner, Rothbart, Sheese, & Tang, 2007; Tang & Tang, 2013; van Veen & Carter, 2002). The ACC and the fronto-insular cortex form part of a network that facilitates cognitive processing through long-range connections to other brain areas (Sridharan, Levitin, & Menon, 2008).

Hölzel, Ott, Hempel, et al. (2007) reported enhanced activation in areas of the ACC in experienced meditators compared to non-meditators during focused attention meditation. Gard et al. (2012) observed similar ACC activation patterns in experienced meditators, compared to a control group, when they anticipated the delivery of a painful stimulus. In addition, Tang et al. (2009) witnessed increased activation of the ventral and rostral ACC in university students, at rest, after completion of a MT intervention. Although ACC activation may be enhanced in early stages of mindfulness practice, it may decrease with higher levels of expertise (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007). Structural magnetic resonance imaging (MRI) research suggest that MT is associated with greater cortical thickness (Grant, Courtemanche, Duerden, Duncan, & Rainville, 2010) and might lead to increased white-matter integrity in the ACC (Tang et al., 2010; Tang et al., 2012).

Functional changes have also been observed in the dorsolateral PFC and parietal regions as a result of MT. Allen et al. (2012) examined functional MRI during performance of the Stroop Task before and after a 6 wk MT intervention. The mindfulness group exhibited greater
dorsolateral PFC response during executive processing, compared to the control group, at post-intervention testing. Allen et al. (2012) concluded that the MT facilitated an increased recruitment of top-down control mechanisms to resolve conflict. In addition, Goldin, Ziv, Jazaieri, Hahn, and Gross (2013), highlighted greater activation in parietal attention regions in social anxiety sufferers following completion of the MBSR intervention.

**Effects of emotion regulation**

Previous researchers have suggested that MT enhances emotion regulation by strengthening prefrontal cognitive control mechanisms that down-regulate activity in regions relevant to affect processing and fear appraisal, such as the amygdala (Hölzel et al., 2011; Tang et al., 2015). Studies have therefore investigated whether MT facilitates a top-down control or facilitated bottom-up processing (Alberto Chiesa, Serretti, & Jakobsen, 2013). Lutz et al. (2014) investigated effects of mindfulness instruction provided during the cued expectation and perception of negative and potentially negative pictures (50% probability) in healthy individuals. The authors observed increased activation in prefrontal areas during the expectation of negative and potentially negative pictures compared to controls. Additionally, during the perception of negative stimuli, reduced activation was observed in the amygdala and parahippocampal gyrus, areas associated with emotion processing. Similar findings were demonstrated by Desbordes et al. (2012) who examined the effect of 8 wk of MT on the amygdala responses to the presentation of positive, negatives and neutral images in healthy individuals. The authors demonstrated a decrease in right amygdala activation in the Mindful group in response to all images, whereas there was no change in the control group. These findings suggest that MT can lead to decreased activation of the amygdala in response to emotional stimuli both at rest and during a mindfulness practice. In contrast, experienced
Meditators have been found to show decreased activation in medial and posterior PFC regions when presented with emotional stimuli (Taylor et al., 2011). Taylor et al. (2011) concluded that long-term practice of mindfulness may lead to emotional stability by promoting acceptance of emotional states and enhanced present-moment awareness.

In elite team-sport, athletes are constantly presented with emotional stimuli, whether it is the mistake of a teammate or a goal scored by the opposition. Therefore, if MT can enhance the down-regulation of areas associated with stress, fear appraisal, and emotion processing, this may be advantageous for athletes during competition.

**Effects on self-awareness**

Findings from recent studies suggest that brain structures supporting self-awareness processing might be affected by MT (Brewer et al., 2011; Farb et al., 2007; Hasenkamp & Barsalou, 2012). Researchers have identified the default mode network (DMN) as the primary region responsible for self-awareness (Buckner, Andrews-Hanna, & Schacter, 2008). This network includes midline structures of the brain, such as areas of the medial PFC, PCC, anterior precuneus and inferior parietal lobule (Northoff et al., 2006; Sajonz et al., 2010). These structures show high activity during rest, as well during mind wandering and conditions of stimulus-independent thought (Northoff et al., 2006). fMRI studies have investigated activity in the DMN in association with MT. Brewer et al. (2011) observed decreased activity in regions of the DMN (i.e., the medial PFC and PCC) in experienced meditators compared to controls across different types of meditation, which they interpreted as decreased self-referential processing and mind wandering. In addition, functional connectivity analysis showed stronger coupling in experienced meditators between the PCC,
dorsal ACC and dorsolateral PFC, both at rest and during meditation. Brewer et al. (2011) concluded that experienced meditators had increased cognitive control over the function of the DMN as compared to non-meditators. Hasenkamp and Barsalou (2012) also found increased functional connectivity between DMN regions and the ventromedial PFC in more experienced meditators, compared to those with less meditation experience. The authors have speculated that the increased connectivity between the DMN and PFC areas supports greater access of the default circuitry to information about internal states as this region is highly interconnected with limbic regions. It could, therefore, be postulated that if MT can decrease mind wandering and increase self-awareness, it could be used as a training tool to improve focus during gameplay in team-sport athletes.

1.2.2 Effects on cognition

The effect of MT on sustained attention has been well established. However it is worth noting that positive effects are only evident when interventions are of adequate duration. Jha, Krompinger, and Baime (2007) investigated the effect of a 1-mo intense mindfulness retreat on sixty individuals with prior meditation experience (4 – 360 mo). This group was compared against seventeen individuals who participated in an 8-wk MBSR program that consisted of weekly meditation sessions of 3 h each, as well as a control group. Although there were no differences observed in sustained attention between the MBSR group and the control group, significant reductions in reaction time (RT) were observed, as measured with the Attention Network Test, in the intensive retreat group as compared with the MBSR group and the controls \( (p < 0.01) \) following the intervention. Another study by Chambers, Lo, and Allen (2008) found similar results when they implemented a 10-d mindfulness Vipassana retreat in a group of twenty healthy individuals. The retreat involved teachings and meditations
sessions accumulating to 10 h for 10 d. Sustained attention was measured before and after the retreat, and compared to a group of controls, using an internal switching task. The results showed significant interaction effects of condition by group \((p = 0.04)\), condition by time \((p < 0.01)\) and time by group \((p = 0.04)\). In contrast to the studies by Jha et al. (2007) and Chambers et al. (2008), other researchers (McMillan, Robertson, Brock, & Chorlton, 2002; Polak, 2009; Tang et al., 2007) have investigated the effect of mindfulness meditation on sustained attention and found no significant effects. However, it must be noted that Tang et al. (2007) used a short, 5-d intervention and, more so, Polak (2009) only implemented a two-session induction. McMillan et al. (2002) focused on effects on traumatic brain injury patients, therefore their condition may have hindered results. In light of these findings, MT interventions of different durations will be explored in the experimental chapters of this thesis.

With regards to selective attention, a previously mentioned study by Jha et al. (2007) reported changes following MT in performance of the Attention Network Test in the MBSR group, but not in the 1-mo retreat group. Other studies have found no effects following interventions, however, intervention duration (Polak, 2009; Tang et al., 2007) or injury condition (McMillan et al., 2002) may have affected the outcomes. Although intervention studies are inconclusive, research comparing regular meditators of differing levels of experience (Chan & Woollacott, 2007), and against controls (Hodgins & Adair, 2010), have demonstrated interesting findings. Chan and Woollacott (2007) assessed selective attention, using a Global Letters Task, in two groups of meditators categorised by minutes of meditation per day \((6 – 150 \text{ min·d}^{-1})\) and total hours \((82 – 19, 200 \text{ h})\), and a control group. The authors demonstrated no correlation between the congruency score and meditation experience. However, the \text{min·d}^{-1} meditation group was associated with faster RT across all trial types that were significant on
a global level ($p < 0.05$). Hodgins and Adair (2010) compared ninety-six meditators (of varying mindfulness practises) against one hundred controls in the Selective attention task, whereby RT were tested on valid, invalid, and neutral cues. Both meditators and non-meditators had faster RT on valid cues versus invalid cues (main effect $p < 0.03$). More importantly, meditators were less challenged by the invalid cues, suggesting that meditators may be able to disengage more efficiently from incorrectly cued visual information and divert their attention to new information.

There is convincing evidence that MT has a positive effect on scores of executive attention. Firstly, Tang et al. (2007) implemented a 5-d, 20-min·d⁻¹ intervention in forty individuals with no previous experience of MT. They were compared against forty controls in the Attention Network Test across sustained (alerting), selective (orienting), and executive (conflict) attention. Although there were no differences found between sustained and selective attention tasks, there was a significant difference in executive attention scores ($p < 0.05$; Figure 1.2). Similarly, Jha et al. (2007) demonstrated that, from baseline testing of the Attention Network Test, there was a significant reduction in conflict monitoring in the retreat group relative to the novice (MBSR and controls) groups ($p < 0.05$) indicating higher levels of executive attention. In support of this, a study aforementioned by Chan and Woollacott (2007) investigated executive attention using the Stroop Task. The authors demonstrated an inverse correlation between meditators characterised by minutes per day and Stroop interference ($r = -0.31, p < 0.05$).
Studies investigating the effects of MT on working memory have implemented interventions of varied doses but all seem to have demonstrated similar findings. Improvements in working memory task performance have been demonstrated in university students following completion of 4-d ($p < 0.01$; Zeidan, Johnson, Diamond, David and Goolkasian, 2010), 10-d ($p < 0.01$; Chambers et al. 2008) and 2-wk (Mrazek, Franklin, Philips, Baird & Schooler, 2013) MT interventions. The authors report similar conclusions; that cultivating mindfulness may be effective for enhancing working memory capacity and reducing mind-wandering. A study by van Vught and Jha (2011) investigated whether a 1-mo MT retreat could enhance working memory in a group of experienced meditators as compared to an age- and education-matched control group. Although accuracy and response time did not differ across the groups ($p = 0.13$; $p = 0.069$, respectively), there was a greater reduction in response time variance
(group x time interaction $p = 0.007$) in the experienced meditators following completion of the 1-mo MT retreat. The authors attributed this to improved information quality and reduced response conservativeness as a result of MT.

Heeren, Van Broeck, and Philippot (2009) investigated the effect of an 8-wk MT intervention on several executive functions in eighteen healthy individuals, with no prior meditation experience. Each individual from the MT group was matched for a control subject, however only group (meditating group, non-meditating group) and condition (pre and post) comparisons were made. Executive functions that were tested included autobiographical memory (Autobiographical Memory Test), cognitive inhibition (Hayling Task), motor inhibition (Go-Stop test), cognitive flexibility (Verbal Fluency Task) and motor flexibility (Trail Making Test). The Autobiographical Memory Test consisted of specific, categorical and extended memory assessment. Interestingly, the only significant improvement made was in the specific category in the meditating group following the MT intervention ($p < 0.01$). The improvements followed, with decreased total error score (pre: 8.83 ± 2.28, post: 0.22 ± 0.54, $p < 0.01$), increased correct responses (pre: 6.38 ± 2.32, post: 10.06 ± 3.02, $p < 0.01$), and decreased one-point error (pre: 8.67 ± 2.38, post: 4.95 ± 3.02, $p < 0.01$) for the Hayling Task in the meditating group. There were no significant improvements in the Go-Stop test or the Trail Making Test, however during the Verbal Fluency Task, the MT group achieved greater correct items on the Semantic Word Fluency (35.98 ± 9.54, 49.56 ± 12.56, $p < 0.01$), Phonemic Word Fluency (25.39 ± 9.05, 34.56 ± 7.04, $p < 0.01$), and the Verb’s Word Fluency (40.56 ± 12.48, 51.33 ± 12.01, $p < 0.01$) components following the MT intervention. A similar study by Zeidan et al. (2010) also found significant positive effects of 4 d of MT (previously mentioned) on tests of complex visual tracking ($p < 0.01$) and verbal fluency ($p < 0.01$). The authors concluded that MT might increase executive functioning.
Considering the studies discussed, there is little doubt that MT can positively affect fundamental aspects of cognition. However, to our knowledge, no research exists examining the effects of MT on cognition in a sporting population. Nevertheless, it is important to understand current research surrounding cognition in sport and external factors that may affect cognition.

1.3 Cognition in sport

Studies have been developed to understand why certain athletes perform at the higher level, revealing that level of performance is correlated with cognitive ability in domains such as vigilance (Janelle & Hatfield, 2008), working memory (BaNKosz, Nawara, & Ociepa, 2013) and decision-making (Vaeyens, Lenoir, Williams, & Philippaerts, 2007). For the purpose of this thesis, each of these cognitive domains have been discussed with respect to their relevance to athletic performance.

1.3.1 Effects of attention on sports performance

According to Starkes and Deakin (1984), success in sport summons a certain degree of concentration and attentional skills to focus on the task at hand. These skills influence an athlete’s ability to process information efficiently and effectively as they affect the information-type selected for processing, and the athlete’s readiness to respond to environmental cues (Janelle & Hatfield, 2008). Whereas information-processing is a fixed reserve, the processes an athlete employs to select cues for attention (i.e., selectivity) and their readiness to respond to different cues (i.e., vigilance) are more dynamic and subject to
change in different situations or in response to different stressors (Baker, Conroy, & Kenney, 2007). As Figure 1.3 eloquently illustrates, attention and an athlete’s ability to ‘select’ from available stimuli is the core component of their sporting performance. It is reasonable to suggest that athletes are inherently trained in vigilance due to the demands of their sport. This is supported by BaŃKosz et al. (2013) who investigated RT in male and female badminton players. They compared the RT of badminton players against non-athletes, in dominant and non-dominant hands, using a MRK-80 reaction meter. Results showed that mean RT was significantly faster in the male badminton players (0.27 s – dominant, 0.27 s – non-dominant) compared to the male non-athletes (0.30 s – dominant, 0.32 – non-dominant). Comparable findings were reported in female athletes (badminton players: 0.26 s for both limbs, non-athletes: 0.30 s for both limbs). The authors concluded that sports-practice was the reason for a faster RT. An earlier, much larger study by Youngen (1959) found the same results in swimmers, fencers, tennis players, and field hockey players, compared to non-athletes. Fontani, Lodi, Felici, Migliorini, and Corradeschi (2006) reported interesting results when comparing karateka and volleyball players, within their disciplines, of differing levels of experience, in several attention tests. They discovered karateka of high experience exhibited significantly faster mean faster RT than the low experience group in the simple RT test ($p < 0.01$), while they performed poorer on the divided attention test ($p < 0.01$). With regards to the volleyball players, the low experience players had faster mean RT than the high experience players on both the simple RT ($p < 0.01$) and divided attention test ($p < 0.01$), however they committed more errors ($p < 0.01$). Although experience did not prevail, even the slowest mean simple RT values of athletes from this study are faster than those of the non-athletes in the study by BaŃKosz et al. (2013; 237 ms; 300 ms, respectively) which further supports that athletes may be inherently trained in vigilance.
Figure 1.3. Conceptual framework for the study of sport expertise depicting the distal (i.e., genetic and cultural) to proximal (i.e., attntional) predictors of superior performance. Source: Janelle and Hatfield (2008)

1.3.2 Role of working memory in sport

According to Bereiter and Scardamalia (1986), ‘experts’ possess a greater ability to grasp new information and utilise it for the execution of skills. They also possess a larger body of knowledge than that of novices, due to their experience, that is more accessible (Anders Ericsson & Smith, 1991). Vaeyens et al. (2007) suggest this superior development of memory skills, in skilled athletes, has promoted rapid encoding of information in their long-term memory, giving them access to that information when required. A previously mentioned
study by BańKosz et al. (2013) also examined differences in working memory in karateka and volleyball players of different experience levels (high and low). Working memory was analysed using the n-BACK test, where participants were presented with a sequence of numbers (1 – 9) randomly on a computer screen. The participant had to press a key when the number shown was the same as the number presented two screens prior. Although no differences in RT and errors were revealed across sports and levels of experience, a strong correlation ($r = 0.918, p < 0.001$) existed between errors, RT, and variability in the highly experienced volleyball players. The authors concluded that in team sports, parameters other than rapidity play a crucial role in characterising highly-skilled athletes such as avoiding incorrect reactions in complex attentional situations (BańKosz et al., 2013). One may also conclude that the highly-skilled volleyball players possess superior ability in high-order cognitive tasks such as decision making.

### 1.3.3 Decision-making in sport

Decision-making in sport has been defined at the process of making a choice from a set of options where the consequence is crucial to performance. In addition, it has been well established that skilled athletes possess superior decision making abilities to those of their less skilled counterparts (Williams, Hodges, North, & Barton, 2006). As previously mentioned, skilled sports performers possess superior perceptual-cognitive skills including that of making correct decisions at any situation during game play (Buszard et al., 2013).

The most prominent sport that has been examined with regards to decision-making ability is soccer. Researchers have designed their own tests to examine the complex interactions between perception, cognition and expertise. Vaeyens et al. (2007) were able to discriminate
forty youth soccer players of comparable experience and competition level based on their decision-making skills during a film-based decision-making test. The results showed that successful decision makers had greater visual search by: i. More time spent fixating the player on possession of the ball, and ii. Alternating their gaze more regularly between the players and other areas of the display. Another study (Williams et al., 2006) using film-based tests identified that more skilled soccer players are faster and more accurate at recognising both familiar and unfamiliar soccer action sequences. There are other studies that have investigated decision-making in team sports such as Australian rules football (Buszard et al., 2013), as well as endurance sports (Renfree, Martin, Micklewright, & Gibson, 2014). Nonetheless, all of these studies have been developed to understand why certain athletes perform at a higher level, in order to design training strategies that can be implemented to improve decision-making, and, ultimately, sports performance.

1.4 Factors impacting cognition

1.4.1 Effects of sleep and circadian rhythm on cognition

Both wakefulness and sleep are regulated by an endogenous circadian clock located in the suprachiasmatic nuclei of the anterior hypothalamus (Van Dongen & Dinges, 2000). It oscillates over a 24-h period and regulates arousal through the action of melatonin secretion and hypocretins. Sleep-wake behaviour is also driven by another process through homeostasis. This increases exponentially with time awake, and dissipates in a similar fashion with sleep. The homeostatic process must be balanced against the circadian element for satisfactory sleep. Along with corresponding messages from the circadian clock, this tells the body it needs to sleep. There is limited evidence of the neural substrate responsible for the
homeostatic process. Some researchers believe adenosine is responsible. As time awake increases, brain glycogen and adenosine triphosphate (ATP) levels are depleted due to metabolic demand. Adenosine is the final product of ATP breakdown and PET studies have shown an up-regulation of adenosine A₁ receptor in humans after prolonged wakefulness. However, rodent studies have shown adenosine is not a direct mediator of sleep, leaving this area of research in dispute. There is no doubt that if we are deprived of sleep, it will have consequential effects on our body. Furthered from this, it can be assumed, and has been well researched, that sleep deprivation has a negative effect on a wide range of our cognitive domains. Sleep deprivation researchers have concluded that vigilance is fundamental to all other aspects of cognition, as Harrison and Horne (2000) conclude that poorer performance in more complex cognitive tasks can be attributed to the inability to sustain attention (i.e., vigilance) to the task at hand. This is supported by Lim and Dinges (2008), who reported that being sleep deprived feels like a force acting on the brain, compelling mental processes to ’switch off’ (i.e., homeostatic effect), resulting in unwanted lapses in attention.

Although the physiological changes, on both on a cellular and molecular level, that occur as a result of sleep deprivation are becoming increasingly well understood, there is little evidence linking neurochemical changes to the regulation of arousal and vigilance. Nevertheless, results studies investigating the effects of stimulants and psychoactive compounds on vigilance, in the presence or absence of sleep deprivation, make for drawing strong conclusions on their relationship. Therefore, during any investigation of cognition, it is a requirement that sleep is controlled.
1.4.2 Effects of stimulants on cognition

The use of caffeine and other stimulants, such as taurine and guarana, to increase human performance is not novel. In sport, they are classified as ‘ergogenic aids’ that have been shown to enhance both physical and cognitive performance. Carvajal-Sancho and Moncada-Jimenez (2005) investigated the effect of an acute dose of an energy drink, containing caffeine and taurine, on speed (100-m sprint), strength (hand dynamometer), power (standing long-jump), RT (eye-hand coordination test), and working memory (Verbal Script Digit Span Test), in twenty male competitive soccer players. Significant effects were found from pre-, to post conditions in the strength and speed components ($p < 0.05$). However, power, RT, and working memory were not affected. The authors concluded that the doses of caffeine (80 mg), taurine (1000 mg) may not have been sufficient to effect mental performance. A more recent study by Hogervorst et al. (2008) investigated the effect of a higher, acute dose of caffeine (100 mg), before, and during (55-, 115-min mark) 2.5-h cycling test at 60% of peak $O_2$ uptake followed by time to exhaustion, in twenty-four well-trained cyclists. This group was compared to two other groups of cyclists who were required to consume a carbohydrate (CHO) bar, or a placebo drink. Cognitive performance (Stroop, Rapid Visual Information Processing, Visual Search, and Word Learning tests) was also measured before and while cycling after 70 and 140 min, and again 5 min after completion. Results showed that cyclists that consumed caffeine had significantly longer time to exhaustion than those who consumed CHO or placebo (27% longer than CHO, $p < 0.03$; 84% longer than placebo, $p < 0.01$). More importantly, cognitive performance was improved significantly across all tests (main effect: $p < 0.01$) with the consumption of caffeine. Although stimulants such as caffeine, taurine, and guarana are not the main interest in this body of work, their effects on cognition have been established and, therefore, have been considered and controlled for to eliminate potential effects.
1.4.3 Effects of exercise on cognition

Dustman et al. (1984) improved neuropsychological function in older-sedentary individuals following a 4-month general strengthening and flexibility program. They concluded that exercise promotes cerebral metabolic activity that helps to prevent the onset of neurological conditions such as Alzheimer’s and Parkinson’s disease. The effect of an acute-exercise bout on cognition remains in question.

A study by Gliner, Matsen-Twisdale, Horvath, and Maron (1978) assessed signal detection vigilance before and after a marathon race in five marathon runners. The results showed significant increases in correct detections in the last quartile (15 min; $p < 0.05$) and significant decreases in false positive detections ($p < 0.01$) from pre to post trials of the signal detection test. It was concluded that Central Nervous System dysfunction is not evident following marathon racing. More recent studies have had similar findings. Hogervorst, Riedel, Jeukendrup, and Jolles (1996) revealed improvements in simple and choice RT, speed of completion of the Colour Word Inference and Stroop tests following prolonged (~60-min) cycle ergometry in male triathletes and cyclists. Moreover, Mcmorris et al. (2003) showed faster mean RT and movement times following a graded cycle-ergometry test performed at 70% and 100% maximum power output.

Tomporowski and Ellis (1986) published a review on the effects of exercise on cognitive processes. They organised studies according to exercise intensity and duration but concluded that there was not enough valid evidence to support the notion that acute exercise effected cognition. A more recent review by Tomporowski (2003) classified studies in a similar fashion, based on type, duration and intensity of exercise protocol employed, however he interpreted the research regarding information-processing. It was concluded that the effects of
acute exercise interventions would only facilitate response time during simple tasks, whereas the influence on complex decision-making or problem solving is insignificant. Tomporowski (2003) also made it evident that participants level of physical fitness, exercise intensity, duration, length of time following exercise, and time of implementation (during or after) of the cognitive task all have differing effects on research results.

**1.4.4 Motivation and mood**

There is no doubt that motivation and mood will affect human performance, in any situation. If an individual is not interested in the environment, or not determined to perform well on the task at hand, then it is almost certain they will not. Conversely, if someone is very motivated, and focused, they are more likely to achieve a better result. It must also be noted that, both in sport and everyday life, individuals are exposed to feelings and stresses that can affect their mood, motivation, or become a distraction to the task at hand, which may then be detrimental to their performance. For example, Parry, Chinnasamy, Papadopoulou, Noakes, and Micklewright (2011) identified higher levels of somatic anxiety, measured using the Competitive State Anxiety Inventory 2 questionnaire, in ironman athletes before the commencement of a race as compared to baseline (baseline: 15, pre-race: 18, \( p < 0.05 \)), and a linear increase in scores of tension from baseline (33), to pre-race (37), and post-race (40). They concluded that the emotional response of these athletes leading up to- and during a race is closely aligned with their conscious thoughts. Although they did not measure cognitive performance, this finding supports the notion that mood and motivation are detrimental to performance, and, as such, have been considered in all experimental chapters of this thesis.
In addition to evaluating whether MT can alter cognitive function, the present thesis has also been directed towards determining whether MT can improve stress and mucosal immune function in athletes. Traditionally, the two most commonly investigated markers of stress and mucosal immune function in sport are cortisol and Immunoglobulin-A (IgA, respectively). For that reason, I have chosen cortisol and IgA as the dependent variables to represent stress and mucosal immune function in this thesis and they will be explored with respect to their function, current research pertaining to sport, in further detail.

1.5 Cortisol

Belonging to the broader class of steroids called ‘glucocorticoids,’ cortisol is considered the ‘stress’ hormone. Circulating cortisol is present under normal resting conditions, and has been shown to exhibit diurnal variation, with maximum levels in the early morning soon after waking (Hucklebridge, Clow, & Evans, 1998). The primary role of cortisol is to restore homeostasis by increasing the availability of glucose in the circulatory system for energy production while inhibiting unnecessary physiological function (i.e., reproduction, innate immune function) during a stressful situation (Hoehn & Marieb, 2010). However, chronic stress can lead to prolonged elevations of cortisol that can also be detrimental to homeostasis (Chyun, Kream, & Raisz, 1984; Djurhuus et al., 2002; Erickson et al., 2003). For the purpose of this thesis, the physiological mechanisms of cortisol will be discussed as well the implications that are associated with chronically elevated circulating cortisol.
1.5.1 Physiology and implications surrounding prolonged elevation in cortisol

In the early fasting state, cortisol stimulates gluconeogenesis and activates anti-inflammatory pathways (Hoehn & Marieb, 2010). Cortisol also plays an indirect role in liver and muscle glycogenolysis, by breaking down glycogen to glycogen-1-phosphorylase and glucose through its passive influence on glucagon. Furthermore, cortisol is essential for the effect of epinephrine on glycogen phosphorylase activation, glycogen synthase inactivation, and glycogen breakdown in resting muscle (Coderre, Srivastava, & Chiasson, 1991). However, chronically elevated circulating cortisol can cause insulin resistance and a chronic hyperglycaemic state (Capes, Hunt, Malmberg, Pathak, & Gerstein, 2001). This is caused by cortisol offsetting the production of insulin and decreasing the translocation of the Glut-4 transporters. Moreover, the link between diabetes, cardiovascular disease, stroke and chronic elevations in cortisol is well established (Rosmond & Björntorp, 2000).

Prolonged cortisol elevation can also have a catabolic effect (i.e., muscle wasting) by increasing proteolysis as well as free fatty acid and amino acid mobilization (Simmons, Miles, Gerich, & Haymond, 1984). Additionally, activation of the Hypothalamic-Pituitary-Adrenal axis will cause inhibition of the Hypothalamic-Pituitary-Gonadal axis, thereby inhibiting the release of the anabolic hormone testosterone. Furthermore, although research has demonstrated that cortisol can have a lipolytic effect (Djurhuus et al., 2002), researchers have identified that cortisol may suppress lipolysis. Tataranni et al. (1996) identified that cortisol can promote the differentiation of preadipocytes into mature adipocytes, increase lipoprotein lipase activity and promote visceral fat storage. Elevated cortisol has also been shown to reduce bone and collagen formation. Chyun et al. (1984) indicated that cortisol
causes an inhibition of proliferation of the periosteal cells that give rise to osteoblasts. Furthermore, it has been shown that increased cortisol is associated with decreases in the amount of mRNA coding pro-collagen chains. Kucharz (1988) reported that cortisol inhibits the activity of specific enzymes of intracellular stages of collagen biosynthesis, therefore, resulting in decreased collagen formation.

With regards to immune function, cortisol inhibits the inflammatory process. It inhibits the production of interleukin (IL)-12, interferon (IFN)-γ, IFN-α and tumour necrosis factor by antigen-presenting cells and T helper (Th)-1 cells (Elenkov, 2004). In turn, cortisol upregulates IL-4, IL-10 and IL-13 by Th2 cells. This results in a shift towards the antibody Th2 immune response rather than general immunosuppression. This process has been perceived as a ‘protective’ mechanism that prevents an over-activation of the inflammatory cytokine response (Elenkov, 2004). However, cortisol can also be detrimental to the immune system. Cortisol has been shown to prevent the proliferation of T-cells by rendering IL-2 producer T-cells unresponsive to IL-1, therefore, making them unable to produce T-cell growth factor. In addition, prolonged elevated cortisol has been associated with decreased serum secretory-Immunoglobulin-A (Posey, Nelson, Branch, & Pearlman, 1978), the primary anti-microbial protein in the mucosal surfaces of the gastro-intestinal (GI) tract. Decreased sIgA has been associated with increased intestinal permeability and GI tract infection (Vanuytsel et al., 2014).

Previous research has highlighted the detrimental effects of chronically high cortisol on cognition. Given the lipo-soluble characteristics of cortisol, it can easily cross the blood brain barrier and bind to receptors in the brain (Erickson et al., 2003). The most concentrated
cortisol-receptor regions of the brain are the hippocampus, amygdala and frontal lobes, in which these regions are associated with memory, learning and affect processing (Lupien, Maheu, Tu, Fiocco, & Schramek, 2007; McLennan, Ihle, Steudte-Schmiedgen, Kirschbaum, & Kliegel, 2016). Although basal levels of circulating cortisol are necessary for normal cognitive function, prolonged exposure to high levels of cortisol has been demonstrated to cause neurotoxic damage and cognitive impairment (Lupien et al., 2007). In line with this, previous studies have highlighted the effects of elevated cortisol levels on declarative memory (de Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2000; Roozendaal, 2002), as well as working memory and executive function (Lupien et al., 2007). Furthermore, prolonged elevations in cortisol have been shown to cause an exaggeration of amygdala activity and an inhibition of prefrontal areas, which has been associated with the onset of anxiety and depression (Davidson, 2002; Gold, Drevets, Charney, & Drevets, 2002).

In summary, the physiological consequences of prolonged elevations in cortisol are unambiguous. Chronic exposure to psychological and physical stress will lead to prolonged elevations in cortisol that may be detrimental to bone and muscle growth, immune function and cognitive function. In sport, athletes are constantly exposed to psychological and physical stressors through training and the pressures of competition. Accordingly, cortisol is the most predominantly measured marker of stress in sporting research.

1.5.2 Cortisol measurement in sport

Cortisol measurement has gained widespread attention in sport because altered secretion, either increased or decreased, may be detrimental to health, well-being and athletic
performance. Accordingly, cortisol measurement has been used to assess an athlete’s response to variations in training load (Jürimäe, Mäestu, Purge, & Jürimäe, 2004), changes in environmental conditions (Bullock, Cox, Martin, & Marino, 2009), and competition (Filaire, Alix, Ferrand, & Verger, 2009; Gonzalez-Bono, Salvador, Serrano, & Ricarte, 1999). Furthermore, previous studies have shown cortisol to be a predictor of training status (Paccotti et al., 2005) and physical effort (Allgrove, Gomes, Hough, & Gleeson, 2008; Hayes, Grace, Baker, & Sculthorpe, 2015; Jacks, Sowash, Anning, Mcgloughlin, & Andres, 2002) as well as a measure of psychological stress (Salvador, Suay, González-Bono, & Serrano, 2003). Although cortisol has been widely measured in sport, the existing research can typically be categorised into three different approaches: 1. Acute responses to exercise and competition, 2. Longitudinal responses to competition and variations in training load, and 3. Anticipatory responses to subsequent competition.

The exercise-induced response in cortisol is well researched with previous studies highlighting the effects of aerobic, anaerobic and power exercise protocols. Numerous studies have highlighted the effects of aerobic exercise on cortisol. Chang, Tseng, Tan, Hsuuw, and Lee-Hsieh (2005) analysed salivary cortisol concentration (sCort) before and after completion of a triathlon race in young-adult and middle-aged trained triathletes. Post-race sCort was significantly higher in both groups, as compared to pre-race measures. However the increase in sCort was significantly greater in the middle-aged triathletes ($p < 0.01$) as compared the younger triathletes ($p < 0.01$). The authors concluded it was likely that the middle-aged triathletes experienced a greater physical stress that was reflected by the greater sCort increase, compared to the younger triathletes. Jacks et al. (2002) examined the effect of three different aerobic exercise intensities (1-h cycling ergometry at 44.5 ± 5.5%, low; 62.3 ± 3.8%, moderate; 76.0 ± 6.0%, high; of VO₂ peak) on sCort measured before exercise, at 10,
20, 40, and 59 min of exercise and after 20 min of recovery in active males. The results showed an increase in sCort at 59 min of exercise \((p < 0.01)\) and 20 min recovery \(p = 0.02\), compared to pre-exercise, in the high-intensity cycling test. In contrast, low- and moderate-intensity cycling had no effects on sCort. Similar findings were reported by Hough, Papacosta, Wraith, & Gleeson (2011) who investigated the effects of four exercise protocols (1. cycling exercise to fatigue at 75% peak power output (FAT), 2. 30-min cycling alternating 1 min at 60% with 1 min at 90% peak power output (60/90), 3. 30 min of cycling alternating 1 min at 55% with 4 min at 80% peak power output (55/80), and 4. Squat exercise comprising 8 sets of 10 repetitions at 10RM (Squat) on plasma and sCort in active men. Only in the FAT and 60/90 exercise protocols did sCort increase pre to post exercise. Both Jacks et al. (2002) and Hough et al. (2011) concluded that only exercise of high intensity will result in significant elevations in sCort. More recent studies have highlighted that short bouts of high-intensity exercise will also elicit an increase in sCort. Crewther, Lowe, Ingram, and Weatherby (2010) observed an increase in sCort after completion of a 30-s Wingate cycling test in active males. Comparable findings were reported by Thomas et al. (2009) who established an increase in sCort in adolescent males after repeated-sprint cycling exercise. Furthermore, the exercise-induced increase in cortisol to resistance training has been well-researched (Kraemer & Ratamess, 2012).

The sCort response in elite athletes before and after competition is similar to previous research that has analysed sCort in response to laboratory-based exercise. Elloumi, Maso, Michaux, Robert, and Lac (2003) investigated the effect of a rugby match on sCort in elite rugby union players. Saliva samples were taken during a rest day and the day of competition at 8 am, 4 pm and 8 pm with the rugby match ending at 4 pm (samples taken post-match). The results showed that sCort measured after the match (4 pm) was two-fold higher (148%, \(p\))
< 0.01) compared to measures taken on the rest day but decreased to resting concentration at 8pm. Lac and Berthon (2000) also evaluated the pattern of sCort during competition in sub-elite male and female runners. They measured sCort before, during (after each relay loop), after and throughout the 2 d following a long distance relay race. The male runners completed eight loops of the relay, whereas the female runners completed six loops. The results showed that sCort gradually increased in the male runners as 7th and 8th relay sCort concentrations were significantly higher than when measured at rest after the 1st relay loop ($p < 0.05$). Female sCort concentrations increased sooner as sCort increased significantly from the 1st to 2nd relay loop. In addition, sCort remained elevated in the evening after the race in both male and female runners as compared to sCort measured in the evening of the 1st and 2nd recovery days. In comparison to the findings of Elloumi et al. (2003), sCort in the runners may have taken longer to subside to resting concentrations (as observed the following morning) due to the longer competition; 6 h of relay running compared to rugby union match. This argument is supported by earlier studies that have suggested that cortisol response is relative to intensity and duration of exercise (Jacks et al., 2002; Lutoslawska, Obminski, Kroguls, & Sendecki, 1991; Snegovskaya & Viru). Nevertheless, both studies were analysing sCort to understand its catabolic properties following competition.

In the studies by Elloumi et al. (2003) and Lac and Berthon (2000), the increase in sCort and its catabolic properties were only ‘short-lived’ as sCort returned to basal concentrations either the evening after or in the days following competition. However, as discussed earlier in this thesis, it is when elevations in cortisol are prolonged that it can be detrimental to health and wellbeing. With respect to athletes, previous studies have highlighted that chronic elevations in cortisol have been associated with overtraining and decreased performance (Eichner, 1995; O’Connor, Morgan, Raglin, Barksdale, & Kalin, 1989). Therefore, researchers have aimed to
understand the longitudinal effects of competition-related stress on cortisol concentration. Handziski et al. (2006) measured resting serum cortisol concentration in elite soccer players before a conditioning phase, as well as before and after a competition phase of a half-season competition. The authors observed a decrease in serum cortisol after the conditioning phase/pre-competition, as compared pre-conditioning measures ($p < 0.05$). However, serum cortisol did increase from pre to post competition ($p < 0.05$) in the elite soccer players. Although Handziski et al. (2006) did not suggest there were any adverse consequences associated with the increase in serum cortisol concentration following competition, this study highlights the relationship between cortisol secretion and competition.

Since sports science research has incorporated cortisol analysis and monitoring in athletes, it has been measured via sampling of blood, urine, hair and saliva. Cortisol measurement in serum and plasma has previously been used to assess overreaching and overtraining training syndrome in athletes (Duclos, Guinot, & Le Bouc, 2007). Plasma cortisol concentrations are modulated by variations of several plasma proteins, primarily by cortisol-binding globulin. However, the concentration of cortisol in saliva is practically free from cortisol-binding globulin and therefore mirrors the concentration of free cortisol in the blood (Lippi et al., 2009). Thus, sCort closely reflects the biological activity of the catabolic hormone in vivo (Laudat et al., 1988). Accordingly, cortisol analysis in the saliva has greatly increased in sporting research as it is non-invasive, repeatable and easily sampled in the athletic field (Lewis, 2006).

Traditionally, salivary analysis has been conducted using bio-sensory immunoassays and Enzyme-linked immunoassay (ELISA) has been considered the ‘gold standard’ saliva
analysis procedure (Fahlman & Engels, 2005; Gleeson, Hall, McDonald, Flanagan, & Clancy, 1999). However, ELISA experimental procedures are comprehensive and time-consuming, and therefore may not be optimal for the applied sport science environment. Hopkins (2000) reported that athlete-monitoring tests should be easy to administer, require minimal technology and be able to obtain highly reliable results. Recently, a novel biosensory device has been developed with the capacity to perform salivary analysis remotely. The Individual Profiling (IPRO, IPRO Interactive, Wallingford, UK) point of care system is a portable immunoassay method that has been reported to reliably determine salivary concentrations of Immunoglobulin-A (i.e., sIgA) and cortisol. Coad, McLellan, Whitehouse, and Gray (2015) demonstrated high reliability with concurrent sampling (ICC = 0.890, CV = 9.4%) as well as validity against the ELISA (r = 0.93, p < 0.01) for resting sIgA concentration in recreationally active individuals. Fisher, McLellan, and Sinclair (2015) reported similar results for resting sCort concentration, establishing duplicate and intra-day reliability (ICCs = 0.868; 0.904, respectively), as well as validity against the ELISA method (p = 0.88) in young healthy adults. These findings support claims that the IPRO can determine sCort and sIgA concentrations consistently across brief (i.e., < 30 min) retest intervals with a high level of validity. Fisher et al. (2015) also evaluated the inter-day reliability of the IPRO to determine sCort at a 7-d retest interval. However, the ICC was 0.685 which is considered ‘questionable’ according to Hopkins (2000). The authors indicated they failed to measure and control for perceived psychological and physical stress; factors that contribute to cortisol secretion at rest (van Eck, Berkhof, Nicolson, & Sulon, 1996). Furthermore, it is unknown whether the study by Fisher et al. (2015) measured and controlled for subjective sleep quality between testing sessions that may have also affected the inter-day reliability of sCort (Backhaus, Junghanns, & Hohagen, 2004). In addition, no previous study has determined the inter-day reliability of sIgA measurement using the IPRO system.
If the IPRO is to be used for the analysis of sCort and sIgA at longer retest intervals, the establishment of a stronger inter-day reliability is warranted. Controlling for perceived stress and sleep quality may be important to minimise the potential influence of these factors normally have on cortisol secretion and, thus, improve and establish the inter-day reliability of the IPRO for sCort and sIgA measurement, respectively.

Indeed, performance tests and analysis systems must demonstrate reliability with repeated assessment under the same conditions (Hopkins, 2000). Moreover, tests must also demonstrate the ability to detect a meaningful change caused by an external factor (i.e., exercise). As discussed previously, maximal exercise has been shown to increase sCort. In addition, high-intensity exercise has been shown to decrease sIgA and will be discussed in further detail. Therefore, it seems plausible to assume that the IPRO will detect changes in sCort and sIgA in response to maximal exercise. Sprint-cycling is considered a reliable mode of exercise as performance and physiological variables have been shown to be reproducible when tests are repeated under the same conditions (Bellinger & Minahan, 2014; Watt, Hopkins, & Snow, 2002). Accordingly, if sCort and sIgA are measured before and after a highly reliable, sprint-cycling protocol, it seems plausible to assume that the sCort and sIgA response to sprint-cycling may also be repeatable. In accordance with this hypothesis, Experiment 4 (Chapter 5) of this thesis examined the inter-day reliability of the IPRO to determine resting sCort concentration and sIgA. In addition, Experiment 4 also examined the reproducibility of the sCort and sIgA response to sprint-cycling exercise.
1.6 Secretory Immunoglobulin-A (IgA)

IgA is the most predominant antimicrobial protein of mucosal immune system and is a major effector of host-resistance to many micro-organisms (Mackinnon & Hooper, 1994). It forms the first line of immunological defence against colonization of infection by neutralizing and preventing viral pathogens from entering the body via the mucosal surfaces (Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006; Tomasi & Plaut, 1985). In the buccal cavity, the synthesis and secretion of sIgA responds almost immediately to stress causing momentary fluctuations in concentration and rate of secretion. IgA can be measured in most mucosal areas as well in serum. However, Tomasi and Plaut (1985) suggest sIgA to be the first barrier to pathogens causing upper respiratory tract infections. Furthermore, sIgA concentration has been shown to correlate more closely to URTI prevalence than do serum antibodies or other immune parameters (Mackinnon & Jenkins, 1993). For these reasons, in addition to the benefits of non-invasive sampling, the majority of sporting research has used salivary analysis for the determination of IgA.

1.6.1 Salivary-IgA measurement in sport

Previous research that has investigated the acute responses of sIgA to training and exercise has produced conflicting results. Several studies have reported decreases in sIgA concentration following various modes of high-intensity exercise, including repeated Wingate tests (Fahlman, Engels, Morgan, & Kolokouri, 2001), interval kayak training (MacKinnon & Jenkins, 1993), a soccer match (Moreira et al., 2009), swimming (Gleeson & Pyne, 2000; Tharp & Barnes, 1990), marathon running (Nieman et al., 2002), and tennis (Novas,
Rowbottom, & Jenkins, 2003). Whereas, some studies have reported no change in sIgA concentration after acute and chronic resistance training (McDowell et al., 1993), as well as treadmill running of varying intensities (McDowell, Hughes, Hughes, Housh, & Johnson, 1992). Conversely, Tharp (1991) reported an increase in sIgA following basketball games in basketball players. The differences in findings are not completely understood. Nevertheless, differences in the expression of sIgA between studies must be considered. Some studies have expressed their findings using only the raw concentration of sIgA in the saliva sample (Tharp, 1991; Tharp & Barnes, 1990), and have not made consideration for the potential of exercise-induced drying of the oral cavity. The studies by Fahlman et al. (2001) and Nieman et al. (2002) attempted to account for the drying effect of exercise by expressing sIgA as relative to total protein. Blannin et al. (1998) reported the preferred method for expressing sIgA is against salivary osmolality, whereas Reid, Drummond, and Mackinnon (2001) reported sIgA as a rate of secretion (µg·min⁻¹). Rate of secretion has commonly been reported in more recent studies (Born et al., 2015; Killer, Svendsen, & Gleeson, 2015; Murase et al., 2015) and will therefore be used to express sIgA in the present study. Moreover, it is known that the sIgA can vary widely between participant groups (Tomasi & Plaut, 1985) making it difficult to compare the previous findings.

Previous longitudinal studies have also monitored sIgA in elite athletes over the course of a competitive season. Gleeson et al. (1995) measured the long-term effect of training on mucosal immune function in elite swimmers. The results indicated a systematic decrease in resting sIgA concentrations that was associated with long-term, high-intensity training. In addition, resting sIgA concentration measured at the beginning of the competitive period significantly correlated with subsequent URTI incidence. Furthermore, the number of URTIs observed during the training period was predicted by the preseason and mean pre-training
IgA concentrations. Gleeson and Pyne (2000) reported similar results by demonstrating a relationship between suppression of basal sIgA concentrations and increased URTI occurrence in elite swimmers during a competition period. Moreover, Fahlman and Engels (2005) observed an increased in URTI incidence during intensive training, and that URTI incidence was inversely related to rate of IgA secretion.

Considering the aforementioned research, when athletes undergo periods of heavy training load, high-intensity exercise, and competition, they are likely to experience elevations in cortisol (i.e., increased stress) and reductions in IgA (decreased mucosal immune function). If recovery strategies are not sufficient, athletes may be left susceptible to illness as well as being faced with the physiological consequences associated with prolonged elevations cortisol concentration at rest. Indeed prolonged elevations in basal cortisol concentration have been linked to overtraining syndrome prevalence in athletes (Kellmann, 2010). Therefore, interventions that have been shown to combat stress and improve function in clinical and healthy populations may also be valuable in the sporting arena. The following sections will explore current research that investigated MT and the effects it has had on stress and immune function.

1.7 The effects of mindfulness training on stress

The efficacy of MT to reduce subjective measures of stress in both clinical and healthy populations is well-established. Furthermore, there is accumulating evidence that MT can cause a reduction in cortisol concentrations. Carlson, Speca, Patel, and Goodey (2004)
investigated the effects of the 8-wk MBSR program on mood, quality of life, stress symptoms, melatonin, dehydroepiandrosterone and salivary cortisol (sCort) concentration in early-stage breast and prostate cancer patients. sCort was collected before and after the intervention across one day at 8 am, 2 pm, and 8 pm. In this sample, approximately 40% of these early stage cancer patients displayed atypical diurnal sCort secretion patterns. This percentage was similar both pre and post intervention, however, a shift did occur from more people displaying a pattern of elevated afternoon sCort concentrations, to a sharper decrease after wakening associated with a lower afternoon concentration, and similar evening concentrations. Carlson, Speca, Faris, and Patel (2007) re-evaluated the same participant group 6 and 12 months later and revealed sCort decreased systematically at six months ($p < 0.05$) and at 12 months ($p < 0.05$). Similarly, Witek-Janusek et al. (2008) examined the effect of the MBSR on plasma cortisol concentration in breast cancer patients. At completion of the MBSR, afternoon measurements of plasma cortisol concentrations were significantly lower ($p < 0.01$) when compared to a control group receiving usual care and also compared to pre-intervention measurement ($p < 0.01$). Together these findings indicate MT has a beneficial effect on diurnal cortisol secretion. Comparable results were also demonstrated when morning sCort was used as a measure of physiological stress. Marcus et al. (2003) investigated the effect of the MBSR on substance abuse sufferers in a therapeutic community setting. They observed a decrease ($p < 0.01$) in morning sCort concentration after completion of the MBSR compared to pre-intervention measures.

Not all MT research has exhibited a positive effect on cortisol measurements. Several previous studies have demonstrated no effects of mindfulness-based interventions on measures of cortisol in healthy and clinical populations. Galantino, Baime, Maguire, Szapary,
and Farrar (2005) reported no changes in sCort concentrations (pre: 0.18 µg·mL⁻¹, post: 0.12 µg·mL⁻¹; \( p = 0.45 \)) in healthcare professionals who completed 8 wk of MT. Robert-McComb, Tacon, Randolph, and Caldera (2004) also observed no difference in serum cortisol concentrations (\( p = 0.34 \)), as compared to a control group, in female cardiovascular disease patients who completed the MBSR program. Furthermore, studies by Klatt, Buckworth, and Malarkey (2009) and Robinson, Mathews, and Witek-Janusek (2003) also reported no changes in salivary- (\( p \) value not given) and serum cortisol concentration (\( p = 0.86 \), respectively) in workers and Human Immunodeficiency Virus (HIV) sufferers (respectively) who completed MT.

Potential reasons for no positive results in the studies aforementioned are already ‘low’ cortisol concentration, intervention duration, and failure to control for confounding variables and disease-state that can affect cortisol secretion. Firstly, it is possible that participants’ pre-intervention cortisol measures in the studies by Galantino et al. (2005) and Robert-McComb et al. (2004) were already at what is considered to be of ‘low’ concentration, leaving no potential for a positive change in response to MBSR. This notion is supported by the previously mentioned findings of Carlson et al. (2004). Although there results revealed no overall changes in mean daily cortisol concentrations, the authors reported that participants with initially elevated cortisol concentrations did have significant reductions (\( p \) value not given) in cortisol following completion of MBSR. Secondly, the study by Klatt et al. (2009) implemented a 6-wk, 1-h weekly session MBSR program (traditionally 8 wk, 2.5-h weekly sessions). Thirdly, attention must be given to the various confounding variables (i.e., diet, exercise, sleep quality etc.) that can independently affect salivary cortisol concentration. Lack of control over confounding variables in the study by Klatt et al. (2009) may explain why they failed to find group differences in sCort concentration between participants who
completed the 6-wk MBSR and the control group. Finally, the study by Robinson et al. (2003) contained participants suffering from HIV. It is well-known that HIV has a harmful effect on the endocrine system and the HPA axis (Desforges, Grinspoon, & Bilezikian, 1992) and is potentially why there were no differences observed in serum cortisol concentration between the group who completed the MBSR and the control group. Furthermore, the authors highlighted this by stating, ‘given the amount of adrenal hormone system dysregulation present in the current sample, it is possible that the effects of the intervention, if any, would have been masked as a result of the disease process itself’ (Robinson et al., 2003). Considering the evidence above, this thesis has controlled for confounding variables as well as only investigating healthy participants and highly-trained athletes to ensure that any changes observed in cortisol concentration are meaningful of MT and not of other external factors. Furthermore, intervention duration has also been explored in the present thesis to establish an ‘effective dose’ of MT that will positively affect cortisol concentration in athletes.

1.8 The effects of mindfulness training on immune function

There is emerging evidence that MT can positively influence immune function in clinical populations. Robinson et al. (2003) examined the effect of the MBSR on perceived stress, mood, endocrine and immune function as well as functional health outcomes in participants infected with HIV. Their results revealed that both natural killer cell activity and natural killer cell number significantly increased ($p = 0.04, p < 0.01$, respectively) in the MBSR group as compared to the control group, when comparing pre and post measures. The authors concluded that the increases in both natural killer cell activity and natural killer cell number were due to the positive effects of stress reduction that potentially lead to either: 1.
modulation of leukocyte trafficking that increased redistribution of cells from immune compartments to the blood, or 2. Alterations in cytokine production (interleukin (IL) -2, IL-12, and IL-18) causing an increase in proliferation and cytotoxicity of natural killer cells. Similar results were found in a study previously mentioned by Witek-Janusek et al. (2008) that supports the conclusions of Robinson et al. (2003). They revealed a systematic increase and decrease in natural killer cell activity and cytokine production (IL-4, IL-6 and IL-10), respectively, in breast cancer patients when measured halfway through-, immediately after- and 4 wk after completion of the MBSR. In contrast, the control group exhibited reductions in natural killer cell activity and continued increase in cytokine production throughout the course of the study. In addition, a more recent study (Creswell, Myers, Cole, & Irwin, 2009) revealed increased CD4+ T lymphocyte production in HIV patients who completed the MBSR, while HIV patients who completed only a 1-d MBSR seminar showed significant reductions in CD4+ T lymphocyte production when comparing pre and post measurements. These findings suggest that MT may have a potential ‘reversing’ effect on stress-associated immune dysregulation in cancer and HIV sufferers.

The positive effects of MT have also been demonstrated on the response to influenza vaccine as well as mucosal immune function. Davidson examined antibody titer activity in response to administration of the influenza vaccine in a group of healthy participants who had just completed the 8-wk MBSR as well a control group. Blood samples were obtained 4 wk and 8 wk after administration of the influenza vaccine. The MBSR group displayed a significantly greater magnitude increase in antibody titers from 4 wk to 8 wk blood samples compared to the control group ($p < 0.05$). In addition, Fan et al. (2010) investigated the effect of Integrated Body-Mind Training, a 4-wk MT intervention (experimental group), as compared to a 4-wk relaxation intervention (control group) on sIgA concentration in healthy university students.
The authors reported an increase in resting sIgA concentrations in the experimental group from baseline to post-intervention ($p < 0.05$), whereas there was no change in the control group. The authors concluded that MT may be an effective tool for enhancing mucosal immune function and, therefore, improving resistance to infection of the upper airways.

The research discussed provides sufficient evidence that MT can reduce stress and improve function in clinical and healthy populations. Considering the importance of optimal recovery from training and competition, MT might be advantageous for elite team-sport athletes in limiting their risk of illness and succumbing to the consequences of chronic stress (i.e., overtraining). The following section presents my knowledge of sport-specific MT interventions and highlights the critical gaps in understanding how MT contributes to enhancing athletic performance.

1.9 Mindfulness training in sport

There is no doubt MT is being used, in some way or another, in the sporting world. Sport psychologists have suggested MT may be useful in sport due to the theoretical overlap between mindfulness and ‘flow’ (Bernier, Thienot, Codron, & Fournier, 2009). As they both share a focus on ‘present experience’ and are often associated to ‘feelings of calmness, serenity, and mind-body unity,’ it has been suggested that MT may allow an athlete to experience flow and therefore achieve higher performance (Gardner & Moore, 2004; Kaufman, Glass, & Arnkoff, 2009). With this in mind, athlete-focused MT interventions have been developed to increase sports performance. Gardner and Moore (2004) created the Mindfulness-Acceptance-Commitment approach, that targets ‘the development of mindful (nonjudgmental) present-moment acceptance of internal experiences such as thoughts,
feelings, and physical sensations, along with a clarification of valued goals and enhanced attention to external cues, responses, and contingencies that are required for optimal athletic performance.’ This approach was implemented by Lutkenhouse, Gardner, and Moore (2007) in a large sample of collegiate athletes, whereby a significantly greater number of athletes received at least a 20% (± 4.7%) improvement in their coach’s subjective ratings of performance, compared to an athletic group who received traditional psychological skills training (p < 0.05). Schwanhausser (2009) reported increases in subjective ratings of mindfulness attention, experiential acceptance, nonjudgmental awareness, dispositional flow (main effect p < 0.01; values not reported) following a 9-wk Mindfulness-Acceptance-Commitment program. Another MT technique is Kaufman’s (2009) Mindful Sport Performance Enhancement program. De Petrillo et al. (2009) examined the effects of a 4-wk Mindful Sport Performance Enhancement program on subjective ratings of perfectionism and running time in elite long-distance runners. The only improvement that was seen following the intervention was in organizational demands, an aspect of perfectionism (pre: 18.32, post: 20.14, p < 0.05). Kaufman et al. (2009) implemented the same 4-wk Mindful Sport Performance Enhancement (MSPE) intervention to investigate its effects on sports performance and subjective ratings of mindfulness and perfectionism in eleven archers and twenty-one golfers. The authors reported no effects on sports performance in golf or archery, and no effects of subjective ratings of mindfulness and perfectionism in the archery group. However, subjective overall mindfulness and dispositional optimism (an aspect of perfectionism) improved following completion of the MSPE intervention (pre: 129.71, post: 138.57, p < 0.01; pre: 19.43, post: 21.14, p < 0.05, respectively).

More recently, Baltzell, Caraballo, Chipman, and Hayden (2014) implemented the 6-wk Mindfulness Meditation Training for Sport program in female collegiate soccer players.
Seven participants were interviewed after completion of the Mindfulness Meditation Training for Sport program and reported an enhanced ability to accept and experience a different relationship with their emotions both on and off the field, as well as increased care for self and team cohesion purposes. In addition, Scott-Hamilton, Schutte, and Brown (2016) investigated the effect of an 8-wk mindfulness training intervention on subject measures of mindfulness, flow and sport-specific anxiety in competitive cyclists. The results revealed a greater increase in mindfulness in the Mindful group as compared to the Control group, when pre and post measures were analysed ($p = 0.04$). Additionally, a greater increase in the frequency of flow ($p < 0.05$) and decrease in sport-specific anxiety ($p < 0.01$) was observed in the Mindful group compared to the Control group. This research provides some preliminary evidence that MT may have positive implications to sport performance. It is noteworthy, however, that studies investigating ‘states’ of mindfulness or MT stands in the blatant contrast with the paucity of utilising more objective correlates to draw conclusions.

A study by John, Verma, and Khanna (2011) investigated the effects of MT on shooting performance and pre-competitive measures of sCort in elite rifle-shooters. The measurement of sCort, followed by rifle shooting was performed before and after completion of a 4 wk of MT (Mindful group) or no training (Control group). The authors reported a decrease in pre-competition sCort concentration in the Mindful group ($p < 0.01$) when comparing pre to post measures. In addition, pre-competition sCort concentration increased in the Control group from pre to post measures ($p < 0.01$). Furthermore, shooting performance improved in the Mindful group (pre: 528 hits, post: 542 hits; $p < 0.01$), whereas there was no change in shooting performance in the Control group (pre: 524 hits, post: 518 hits; $p > 0.05$). This study indicates that MT can attenuate the acute anticipatory increase in sCort related to competition and improve shooting performance in elite rifle shooters. Although it can now be postulated
that MT can attenuate pre-competition stress-related increases in salivary cortisol, it is unknown whether MT will have the same effect on resting concentrations on sCort if athletes were submitted to the physical and psychological demands of regular or extended competition (i.e., competition period).
1.10 General aims of this thesis

The principle purpose of this thesis is to ascertain whether MT can improve cognitive performance, reduce stress and improve mucosal immune function in team-sport athletes. Given that various areas of cognition have been demonstrated as critical elements to successful decision-making during sport performance, a test that can reliably assess the fundamental aspects of cognition is warranted. Neurocognitive tests designed for monitoring recovery from concussion injury have been shown reliable in athletes. However, a more complex test may be required to identify changes elicited by an intervention (i.e., exercise, MT etc.). In addition, if MT can improve cognitive performance in non-athletic population groups, the potential for an improvement in team-sport athletes is worth considering. Nevertheless, before we can recommend the implementation of MT into the training programs of team-sport athletes, we need to explore effective doses of MT and whether there are improvements in cognitive performance after a single meditation session and/or a training intervention. Although the IPRO has demonstrated intra-day reliability and validity for measuring sCort and sIgA, inadequate data are available on the inter-day reliability of this salivary analysis of this technique. In addition, little is known whether the IPRO is sensitive enough to detect changes in sCort and sIgA that are commonly associated with interventions such as high-intensity exercise. Furthermore, sCort and sIgA measurement present useful monitoring tools for the management of training and competition loads as well appropriate recovery strategies during a competition period. Currently, there is evidence that mindfulness training can reduce sCort and sIgA in clinical and healthy populations. In addition, mindfulness training has been shown to attenuate anticipatory increases in sCort before competition. However, it remains to be determined whether MT can attenuate the chronic increase in resting sCort in a group of team-sport athletes during a period of competition.
Furthermore, it remains to be determined whether MT can improve resting sIgA in team-sport athletes during competition.

**Aim one:** To evaluate the intra and inter-day reliability of cognitive performance using a computer-based test battery in team-sport athletes (approached in Chapter 2, Experiment 1).

**Aim two:** To determine the immediate effects of a mindfulness meditation session on fundamental aspects of cognition in team-sport athletes (approached in Chapter 3, Experiment 2).

**Aim three:** To determine the effect of MT on fundamental aspects of cognition in a team of trained rugby union players (approached in Chapter 4, Experiment 3).

**Aim four:** To evaluate the inter-day reliability of the IPRO method for determining resting and post-exercise salivary cortisol (sCort) and rate of Immunoglobulin-A (sIgA) secretion in active males (approached in Chapter 5, Experiment 4).

**Aim five:** To determine the effect of 8 wk of MT on salivary cortisol (sCort) and rate of Immunoglobulin-A (s-IgA) secretion in wheelchair-basketball players while they completed a 7-wk competition period (approached in Chapter 6, Experiment 5).

Participants in Experiments 1, 2, and 3 were recruited by method of presenting to athletes and coaches at the Queensland Reds Rugby Union Club. Participants in Experiment 4 were recruited by handing out flyers to university students at the Griffith University Gold Coast campus. Participants were recruited for Experiment 5 following presentations to athlete
squads within the Queensland Academy of Sport. Athletes and individuals who were willing to participate contacted the Chief and Co-investigators for further information and, only after medical history screening and informed consent were they able to participate in the experiments. All participants in the present experiments were either highly-trained male and female team-sport athletes, or healthy active males aged between 18 and 50 yr.
Chapter 2: Indices of cognitive function measured in rugby union players using a computer-based test battery

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2.1 Abstract

The purpose of this study was to investigate the intra and inter-day reliability of cognitive performance using a computer-based test battery in team-sport athletes. Eighteen elite male rugby union players (age: 19 ± 0.5 yr) performed three experimental trials (T1, T2 and T3) of the test battery: T1 and T2 on the same day and T3, on the following day, 24 hr later. The test battery comprised of four cognitive tests assessing the cognitive domains of executive function (Groton Maze Learning Task), psychomotor function (Detection Task), vigilance (Identification Task), visual learning and memory (One Card Learning Task). The intraclass correlation coefficients (ICC) for the Detection Task, the Identification Task and the One Card Learning Task performance variables ranged from 0.75 to 0.92 when comparing T1 to T2 to assess intra-day reliability, and 0.76 to 0.83 when comparing T1 and T3 to assess inter-day reliability. The ICC’s for the Groton Maze Learning Task intra and inter-day reliability were 0.67 and 0.57, respectively. We concluded that the Detection Task, the Identification Task and the One Card Learning Task are reliable measures of psychomotor function, vigilance, visual learning and memory in rugby union players. The reliability of the Groton Maze Learning Task is questionable (mean CV = 19.4%) and, therefore, results should be interpreted with caution.
2.2 Introduction

Expert team-sport athletes must be proficient in: 1. Attending to important environmental information, 2. Recognising and recalling patterns of play, and 3. Making correct decisions during match play (Buszard et al., 2013; Roca et al., 2013). Therefore, cognitive performance in the areas of attention, working memory, and executive function are crucial to athletic proficiency. Sports Scientists are now using neurocognitive tests to investigate the cognitive performance of expert athletes. Furthermore, cognitive performance in domains such as vigilance, working memory, and decision-making have been previously reported to be positively correlated with athletic proficiency in team sports such as volleyball (Fontani, Lodi, Felici, Migliorini, & Corradeschi, 2006) and soccer (Savelsbergh, Williams, Kamp, & Ward, 2002; Vaeyens et al., 2007).

Recently, there has been a development of computer-based neurocognitive tests that measure cognitive performance. Falleti, Maruff, Collie, and Darby (2006) report that tests should be standardised, have brief administration time, possess multiple variations in test delivery, and produce data suitable for statistical analyses. They should also demonstrate reliability with repeated assessment under the same conditions (Hopkins, 2000). According to Hopkins (2000), reliability of a performance test is determined by: 1. Changes in mean value, 2. Retest correlation, and 3. Within-participant variation. Changes in mean value specify the magnitude of change with respect to the first performance trial. Regarding cognitive test reliability, this may reveal any potential practice effects or mental fatigue augmented by subsequent trials. Retest correlation characterizes how the rank order of participants in the first trial is simulated in successive trials. Within-participant variation is the most significant reliability measure as it determines the accuracy of estimates of change in the outcome variable of a study. This serves as an important reliability measure in tests used by coaching staff and
Sports Scientists to monitor changes in performance of their athletes. In a sporting setting, a small within-participant variation would make it easier to identify a “meaningful” change in athletic performance (Hopkins, 2000). The reliability of cognitive performance in a sporting population has previously been established using neurocognitive tests designed for monitoring recovery from concussion injury (Collie et al., 2003; Louey et al., 2014). However a more complex test may be required to identify changes in cognitive performance in healthy athletes following interventions in such areas as nutrition, pharmaceuticals, or psychology.

CogState (CogState Ltd, Melbourne, VIC, Australia) is a computerized battery that has been developed specifically for repeated cognitive testing and is currently being used in many areas of clinical research, including Alzheimer’s disease (Pietrzak et al., 2015), Schizophrenia (Knott et al., 2015), pharmacology (Chen et al., 2015), and alcohol (Charlton & Starkey, 2015). The CogState battery contains tests that have been shown to validly measure a wide range of cognitive domains (i.e., psychomotor function, working memory, learning etc.; Westerman, Darby, Maruff, & Collie, 2001) some of which have been highlighted to contribute to a team-sport athlete’s performance. However, to our knowledge, the reliability of the CogState computerized battery of tests has never been established in a sporting population. If it is to be used by Sports Scientists and coaches, any perturbations in cognitive performance in athletes can then be considered meaningful of the external factor of particular interest (e.g., sleep quality). The purpose of the present study was to examine the test-retest reliability of assessing cognitive performance using the CogState battery in young, team-sport athletes.
2.3 Methods

2.3.1 Participants

Eighteen male rugby union players (age: 19 ± 0.5 yr) were recruited for the current study. All participants were free from, or had not suffered a concussion for more than 12 months. Participants were considered highly-trained, completing > 12 h·wk⁻¹ of training while playing in a state under 20’s representative rugby union team. All participants were informed of the study requirements and provided written informed consent. The study was conducted at the training grounds of the rugby union club and was approved by the Griffith University Human Research Ethics Committee.

2.3.2 Experimental design

Participants attended the training grounds on three separate occasions at the same time of day (± 1 h). Day 1, 2 and 3 were separated by > 24 h. All sessions were completed in the same room of the rugby union club whereby temperature (24 - 25°C) and humidity (55 – 60%) were maintained during testing. Day 1 of testing consisted of familiarisation of the test battery. To assess both intra- and inter-day reliability, participants completed two trials of the test battery, separated by 30 min, on Day 2, and a final trial, at the same time of day (± 30 min) on Day 3.

Prior to completion of testing, each participant was asked to abstain from alcohol for a period of 12 h. Participants were required to record a 24-h diet diary leading up to testing on Day 2 which was then replicated preceding testing on Day 3. They were also required to record a 24-h sleep scale prior to completion of Day 2 and Day 3 to ensure similar sleep patterns from
the nights prior to testing. Adherence to these requests was confirmed by each participant prior to the completion of each session.

2.3.3 Apparatus

For completion of all trials, participants were seated in an upright posture and at the same individual desk. Desks were also positioned so that participants would not experience any visual distractions during testing. The test battery, CogState (CogState Ltd., Melbourne, VIC, Australia), was presented on a Lenovo T420 14' Notebook (Core i5 processor, 2.5 GHz, Lenovo Group Ltd., Morrisville, USA) complete with headphones for audible cues and to eliminate audible distractions. All tests within the battery were adaptations of standard neuropsychological and experimental psychological tests. The battery required approximately 10 min to complete and consisted of four tests presented in succession. Written instructions were presented on the screen prior to beginning of each test along with an interactive demonstration. The four individual tests, in their order of presentation, are as follows:

**The Groton Maze Learning Task.** This is a test of executive function. The participant was shown a 10 x 10 grid of tiles on the computer screen. A 28-step pathway was hidden among the one-hundred possible locations. The start was indicated by the blue tile at the top left and the finish location was the tile with the red circles at the bottom right of the grid. The participant was instructed to move one step from the start location and then to continue, one tile at a time, toward the end (bottom right). The participant moved by left-clicking the mouse cursor on a tile next to their current location. After each move was made, the computer indicated whether this was correct by revealing a green check mark (i.e., this is the next step in the pathway), or incorrect by revealing a red cross (i.e., this is not the next step in the
pathway, or the participant had broken a rule, see below). If a choice was incorrect (i.e., red cross revealed), the participant had to click on the last correct location (i.e., the last green check mark revealed) and then make a different tile choice to advance toward the end. While moving through the hidden maze, the participant was required to adhere to two rules. Firstly, the participant could not move diagonally or touch the same tile twice in succession. Secondly, the participant could not move backwards along the pathway (e.g., move back to a location that displayed a green tick, but from which they had since moved on from). If the participant chose a tile that was not part of the hidden pathway, but the tile choice was within the rules, this was recorded as a different type of error (i.e., not a rule break). This could have been due to chance (i.e., the first time through the maze) or due to not remembering the path on subsequent attempts. The participant learnt the 28-step pathway though the maze on the basis of this trial and error feedback. Once completed, they returned to the start location and was required to repeat the task four more times, trying to remember the pathway they had just completed. The primary outcome measure for this test is total errors made from the five attempts at the maze, with a lower score indicating greater performance.

The Detection Task. This is a test of psychomotor function. Participants were required to maintain vigilant attention on a deck of cards presented face down on the screen. They were required to respond as quickly as possible when the front card turned face-up, by pressing the key, and had to avoid responding prematurely. The participant was shown a total of thirty-five cards during the Detection Task. However, a post-anticipatory response would initiate an extra card to be shown during the test. The primary performance variable for this test is the mean speed of correct responses presented in milliseconds. The 20% and 40% fastest reaction times (20% Fastest RT, 40% Fastest RT, respectively), presented in milliseconds, have been chosen as the secondary performance variables.
**The Identification Task.** This is a test of vigilance. The pre-task on-screen instructions asked, “Is the card red?” A deck of cards was presented in the centre of the computer screen face down. When the card flipped over, the participant had to respond, as quickly as possible, by either pressing the *k* key (yes) if the card was red or the *d* key (no) if the card was black. If the participant made an incorrect or premature response, they heard an error sound. The participant was shown a total of thirty cards during the Identification Task. However, a post-anticipatory response initiated an extra card being added to the test. The primary performance variable for this test is the mean speed of correct responses (i.e., choice reaction time) presented in milliseconds. The 20% and 40% fastest reaction times (20% Fastest RT, 40% Fastest RT, respectively), presented in milliseconds, have been chosen as the secondary performance variables.

**The One Card Learning Task.** This is a test of visual learning and memory. The pre-task on-screen instructions asked, “Have you seen this card before in the task?” A deck of cards was presented in the centre of the screen face down. Each time a card was revealed, the participant had to determine whether they had been shown that card before in the task and respond by pressing either the *k* key (yes) if they believe they had seen the card or the *d* key (no) if they believe they had not. If an incorrect response was given (i.e., *no* was pressed when a card had been presented before) an error noise was heard. The One Card Learning Task had a total of eight rounds. In each round, there were ten cards shown. Of those ten cards, four of them were repeated (i.e., probes) and the other six were not (i.e., foils). The same four cards were repeated during each round. The idea is that the participant learnt of the cards repeating during each round and their performance increased as the test continued. The primary outcome measure of this task is the number of correct responses expressed as a
percentage of the total trials (accuracy). The secondary performance variable for this task is mean speed of correct responses, presented in milliseconds.

2.3.4 Data Analysis

Data were log transformed and analysed using an excel spreadsheet for reliability as described by Hopkins and colleagues (2000). Intra- (Trial 1 and 2) and inter-day (Trial 1 and 3) reliability were analysed using intra-class correlations. An individual’s coefficient of variation (CV) for a specific outcome variable was calculated as the standard deviation of an individual’s repeated measurement, expressed as a percentage of their individual mean score. Typical error is presented as the CV % and as an absolute value along with the upper and lower 90% confidence interval (CI). Statistical significance was set at $p < 0.05$. It must be noted that one participant’s results from the Groton Maze Learning Task was excluded prior to data analysis due to observed distraction during testing.

2.4 Results

Mean performance variables, for each individual cognitive test of the battery, for each trial, are shown in Table 2.1. All reliability measures are shown in Table 2.2. The mean intraclass correlation coefficients for all four tasks across the three trials ranged from 0.62 – 0.84. The intra-class correlation coefficients from T1 and T2 ranged from 0.67 – 0.92, and 0.57- 0.83 from T1 to T3. The mean reliability, expressed as the coefficient of variation (CV; %) and the typical error of measurement over the three trials were total errors 19.4%, 4.8 (95% CL 3.7-6.8) for the Groton Maze Learning Task; mean speed 4.2%, 12.7 ms (95% CL 9.9-17.7), 20% fastest RT 4.0%, 9.7 ms (95% CL 7.6-13.6) and 40% fastest RT 3.3%, 8.6 ms (95% CL 6.8-12.1) for the Detection Task; mean speed 6.0%, 28.4 ms (95% CL 20.3-36.3), 20% fastest RT
5.2%, 18.2 ms (95% CL 14.3-25.5) and 40% fastest RT 5.4%, 20.1 ms (95% CL 15.8-28.2) for the Identification Task; accuracy 4.0%, 3.0% (95% CL 2.3-4.1) and mean speed 6.9%, 61.7 ms (95% CL 48.4-86.2) for the One Card Learning Task. Figure 2.1 illustrates the differences from the mean of the three trials for the primary performance variables for the Groton Maze Learning Task, Detection Task, Identification Task and the One Card Learning Task.

Table 2.1. Mean (SD) performance variables for each individual task from three trials of the cognitive test battery

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GMLT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total errors</td>
<td>41.2 (13.7)</td>
<td>34.7 (14.3)</td>
<td>37.2 (9.3)</td>
<td>37.7 (12.4)</td>
</tr>
<tr>
<td><strong>DET</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>290.5 (35.3)</td>
<td>295.4 (32.9)</td>
<td>297.2 (23.5)</td>
<td>294.2 (30.6)</td>
</tr>
<tr>
<td>20% Fastest RT (ms)</td>
<td>246.1 (24)</td>
<td>248 (24)</td>
<td>246.7 (19)</td>
<td>246.9 (22.3)</td>
</tr>
<tr>
<td>40% Fastest RT (ms)</td>
<td>256 (24.2)</td>
<td>260.3 (23.7)</td>
<td>258.6 (17.3)</td>
<td>258.3 (21.7)</td>
</tr>
<tr>
<td><strong>IDN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>429.8 (56.9)</td>
<td>457.9 (59)</td>
<td>444.9 (41.6)</td>
<td>444.2 (52.5)</td>
</tr>
<tr>
<td>20% Fastest RT (ms)</td>
<td>357.5 (44.8)</td>
<td>371.8 (38.7)</td>
<td>365.9 (29.2)</td>
<td>365.1 (37.6)</td>
</tr>
<tr>
<td>40% Fastest RT (ms)</td>
<td>376.5 (49.2)</td>
<td>394.8 (43.5)</td>
<td>385.9 (30.3)</td>
<td>385.7 (41)</td>
</tr>
<tr>
<td><strong>OCL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>73.5 (5.4)</td>
<td>76.9 (6)</td>
<td>77.2 (5.8)</td>
<td>75.9 (5.7)</td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>851.6</td>
<td>839.7 (120)</td>
<td>810.8</td>
<td>831.4</td>
</tr>
</tbody>
</table>

Table 2.2. Mean within subject intraclass correlation (ICC), typical error expressed as a coefficient of variation (CV %) and an absolute value (TEM) of the between-tests change

<table>
<thead>
<tr>
<th></th>
<th>ICC (1-2)</th>
<th>ICC (1-3)</th>
<th>ICC (Mean)</th>
<th>CV (1-2)</th>
<th>CV (1-3)</th>
<th>CV (Mean)</th>
<th>TEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GMLT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20% Fastest RT</td>
<td>.86 [.72, .94]</td>
<td>.77 [.55, .89]</td>
<td>.82 [.64, .92]</td>
<td>3.7 [2.9, 5.2]</td>
<td>4.3 [3.3, 6.0]</td>
<td>4.0 [3.1, 5.6]</td>
<td>9.7 [7.6, 13.6]</td>
</tr>
<tr>
<td>40% Fastest RT</td>
<td>.92 [.83, .97]</td>
<td>.76 [.53, .89]</td>
<td>.84 [.68, .93]</td>
<td>2.6 [2.0, 3.6]</td>
<td>4.0 [3.1, 5.6]</td>
<td>3.3 [2.6, 4.6]</td>
<td>8.6 [6.8, 12.1]</td>
</tr>
<tr>
<td><strong>DET</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Speed</td>
<td>.76 [.53, .89]</td>
<td>.76 [.52, .89]</td>
<td>.76 [.53, .89]</td>
<td>6.2 [4.9, 8.8]</td>
<td>5.7 [4.5, 8.1]</td>
<td>6.0 [4.7, 8.5]</td>
<td>28.4 [20.3, 36.3]</td>
</tr>
<tr>
<td>40% Fastest RT</td>
<td>.77 [.54, .89]</td>
<td>.80 [.60, .91]</td>
<td>.79 [.57, .90]</td>
<td>5.8 [4.6, 8.3]</td>
<td>4.9 [3.8, 6.9]</td>
<td>5.4 [4.2, 7.6]</td>
<td>28.2 [15.8, 48.2]</td>
</tr>
<tr>
<td><strong>IDN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Speed</td>
<td>.81 [.61, .91]</td>
<td>.70 [.42, .85]</td>
<td>.76 [.52, .88]</td>
<td>3.6 [2.8, 5.1]</td>
<td>4.4 [3.4, 6.2]</td>
<td>4.0 [3.1, 5.7]</td>
<td>3.0 [2.3, 4.1]</td>
</tr>
<tr>
<td>20% Fastest RT</td>
<td>.88 [.74, .94]</td>
<td>.73 [.48, .87]</td>
<td>.81 [.61, .91]</td>
<td>5.8 [4.5, 8.2]</td>
<td>7.9 [6.2, 11.2]</td>
<td>6.9 [5.4, 9.7]</td>
<td>61.7 [48.4, 86.2]</td>
</tr>
</tbody>
</table>

*Note: GMLT = Groton Maze Learning Task, DET = Detection Task, IDN = Identification Task, OCL = One Card Learning Task.*
2.5 Discussion

In the present study we found that selected indices of cognitive performance measured using a computer-based test battery (i.e., CogState) are reliable in team-sport athletes. Cognitive performance in the domains of executive function, psychomotor function, vigilance, visual learning and memory did not change across three trials of the test battery in rugby union players. The intraclass correlation coefficients for all performance variables ranged from 0.67 to 0.92 when comparing T1 to T2 to assess intra-day reliability, and 0.57 to 0.83 when comparing T1 and T3 to assess inter-day reliability. In particular, the Detection Task, Identification Task and One Card Learning Task performance variables, relating to the cognitive domains of psychomotor function, vigilance, visual learning and memory, all showed ICC’s of above 0.73 indicating “acceptable” to “good” reliability (Hopkins, 2000). The mean ICC for Groton Maze Learning Task was 0.62 indicating “questionable” reliability and, therefore, results should be interpreted with caution. A larger sample size in the present study may have improved the reliability of the cognitive test. However, the present study demonstrates the reliability of a computer-based battery of cognitive tests in a single team of athletes who are matched for age, training status and competition level, therefore providing greater external generalisability.
It is worth noting that the cognitive tests in the present study have been designed to measure fundamental cognitive skills although tests such as these have been criticized for not being able to capture the complexities of the team-sport environment that generate expert performance (Ericsson & Starkes, 2003). There is conflicting evidence surrounding the capacity of ‘basic’ tests (i.e., reaction time-type tests) to differentiate ability in team-sport athletes (Bosel, 1998; Castiello & Umiltà, 1992; Helsen & Starkes, 1999). However, a meta-analysis by Voss, Kramer, Basak, Prakash, and Roberts (2010) has highlighted the relevance of these tests as having “important implications for capturing and characterising the
fundamental cognitive skills associated with competitive sport training.” Therefore, although the Detection Task and Identification Task may not identify expert athletic performance, they will still serve an integral role in the CogState battery in assessing an athlete’s fundamental cognitive skills. Voss et al. (2010) also concluded that future research study designs should implement ‘higher-level’ cognitive tests indicating that the Groton Maze Learning Task and One Card Learning Task may differentiate ability in rugby union players. Further research is warranted to determine this. It should also be noted that the four tests were completed in the same order for every subject; thus, potential carry-over effects may be present in the reliability data that should be considered by anyone using this cognitive test battery or reporting the reliability data for a single test.

The present study suggests what could be considered a worthwhile change (Hopkins, 2004) in performance of the CogState test battery in response to a certain effect (i.e., exercise) in rugby union players. For example, given the typical error of 4.2% for mean speed on the Detection Task, coaches and athletes would be ‘reasonably confident of a worthwhile change’ (Hopkins, 2004) where an increase in mean speed of 2.1% (i.e., half the typical error) or 6 ms is observed. According to Hopkins (2004), athletes should aim to improve by double the typical error (i.e., 8.4% for mean speed), or 25 ms, from an initial mean speed of 294 ms. However, the duration or percent of improvement in mean speed of the Detection Task, in order to make an impact on performance, is unknown. Furthermore, the typical error value was derived from a relatively small number of rugby union players. Therefore, further research may determine what could be considered a ‘biological change’ in determinants of cognitive performance.
The reliability of cognitive performance in a sporting population has previously been assessed using a neurocognitive test similar to CogState used in the present study. CogSport/Axon is designed to assess recovery from sports-related concussion (Louey et al., 2014). It contains four tests, three of which are shortened versions of the Detection Task (15 card presentations compared to 35 in the present study), Identification Task (15 card presentations compared to 30 in the present study) and One Card Learning Task (40 card presentations compared to 80 in the present study). Louey et al. (2014) investigated the reliability of CogSport/Axon in AFL and rugby union players, revealing ICC’s of 0.85 for Detection Task mean speed, 0.86 for Identification Task mean speed, and 0.93 for One Card Learning Task accuracy at a 7-d retest interval. These findings indicate higher reliability when compared to ICC’s from T1 to T3 for Detection Task mean speed (0.78), Identification Task mean speed (0.76), and One Card Learning Task accuracy (0.70) in present study. However, CogSport/Axon contains tests of shorter duration and has only been designed to identify and monitor concussion recovery. Furthermore, the study by Louey et al. (2014) had a much larger sample size (n = 235) compared to the present study (n = 18). Therefore, although CogSport/Axon appears more reliable, it is difficult to compare to CogState as it may be a much simpler test for the healthy athlete. Collie et al. (2003) assessed the reliability of an older version of CogSport/Axon (formerly known as CogSport) at 1-h and 1-wk retest intervals in healthy individuals. The ICC’s for psychomotor mean speed at 1-h and 1-wk intervals were 0.90 and 0.76, respectively. The findings Collie et al. (2003) are similar to the reliability of the Detection Task performance variable, mean speed, in the present study with ICC’s of 0.90 (T1 and T2) and 0.78 (T1 and T3). In reference to choice reaction time, we found higher reliability for the Identification Task performance variable of mean speed at 30-min (ICC 0.76) and 24-h (ICC 0.76) retest intervals in comparison to Collie et al. (2003) who
reported lower ICC’s of 0.69 and 0.69 for mean speed during the choice reaction time task at 1-h and 1-wk intervals, respectively.

A study by Collie, McCrory, and Makdissi (2006) investigated the association between cognitive performance and self-reported history of concussion in elite Australian Football League (AFL) athletes also using CogSport. The mean speed recorded for simple reaction time and choice reaction time in the AFL athletes with no previous history of concussion (288.5 ms, \(SD = 67.4\), 438.3 ms, \(SD = 106.7\), respectively) was similar to the mean speed recorded for both the Detection Task and the Identification Task across all trials (294.2 ms, \(SD = 30.6\), 444.2 ms, \(SD = 52.5\), respectively) in the Rugby Union players in the present study. Such closely matched performance in reaction time tasks between the two athlete groups could be attributed to their similar sporting demands and game situations. Furthermore, it may be possible that team-sport athletes are inherently trained to respond faster to a stimulus than non-athletes. A study by Falleti et al. (2006) administered repeated trials of the CogState battery in two groups of healthy individuals. The battery used by Falleti et al. (2006) varied to that in the present study as it contained eight tasks, each of shorter duration. Their battery did, however, contain a shortened version of the Detection Task (15 card presentations compared to 35 in the present study) and the Identification Task (15 card presentations compared to 30 in the present study). When values were antilogarithm transformed, the first group recorded mean reaction times of 299.27 ms and 489.78 ms on the Detection Task and the Identification Task, respectively. Moreover, the second group recorded mean reaction times of 323.59 ms on the Detection Task and 520.79 ms on the Identification Task. These values are much slower than those achieved by the AFL players (Detection Task = 288.5 ± 67.4 ms, Identification Task = 438.3 ± 106.7 ms) in the study by Collie et al. (2006) and the rugby union players (Detection Task = 294.2 ± 30.6 ms,
Identification Task = 444.2 ± 52.5 ms) in the present study. It is also worth highlighting the mean age of participants in the first group was 21.6 years (± 3.8) while the second group was 32.7 years (± 9.6). The older average age of the second group in the study by Falleti et al. (2006) may explain the slower reaction times due to the effect of aging on cognition (Fozard, Vercruysse, Reynolds, Hancock, & Quilter, 1994). However, it is difficult to make these assumptions due to the differences in the cognitive tests that were administered by Falleti et al. (2006) compared to those in the present study. Nonetheless, further research is warranted to determine whether differences in cognitive performance exist between athletes and non-athletes.

The reliability of the CogState battery has previously been assessed in healthy individuals by Falleti et al. (2006). They reported ICC’s of 0.94 and 0.73 for mean speed recorded from performance of the Detection Task, and 0.81 and 0.71 for mean speed from performance of the Identification Task at retest intervals of 10 min and 1wk (respectively). We reported similar findings with ICC’s 0.90 and 0.78 (mean speed; Detection Task), 0.76 and 0.76 (mean speed, Identification Task) at 30 min (T1-T2) and 24 h (T1-T3) retest intervals. This indicates acceptable trial-to-trial and day-to-day reliability when assessing vigilance and choice reaction time in both healthy and sporting individuals using the CogState battery.

Only in older populations has the reliability of the One Card Learning Task been assessed. Lim et al. (2013) assessed the reliability of a CogState battery, containing six tasks including the One Card Learning Task from the present study, in a group of 105 healthy older adults in 1-mo retest intervals. They reported a mean ICC of 0.77 for accuracy in the One Card Learning Task across all trials. This is very similar to the mean ICC (0.76) for accuracy in the One Card Learning Task in the present study. To our knowledge, only one study has
investigated the reliability of the Groton Maze Learning Task in a cognitive test battery. Dingwall, Lewis, Maruff, and Cairney (2009) assessed the reliability of a CogState battery, containing seven tasks including the Groton Maze Learning Task, in healthy adolescents. The battery was administered four times at approximately 14-d intervals. Pearson’s correlation coefficients were calculated to reveal a mean $r$ value 0.60, for total errors in the Groton Maze Learning Task across the four trials, and, therefore, demonstrated “acceptable” reliability (Dingwall et al., 2009). In the present study, a mean ICC of 0.62 for total errors in the Groton Maze Learning Task was reported for all trials. However, due to the difference in reliability analyses, it is difficult to compare the present findings with those of Dingwall et al. (2009).

The ability of a Rugby Union player to read the play and make fast, correct decisions while maintaining a good focus on the game is crucial to their own and their team’s performance. We can only hypothesize about the relationship between performance on a computer based cognitive battery and a player’s ability to perform on the field. Nevertheless, the development of reliable tests for the assessment of cognitive performance in such domains as psychomotor function, vigilance, visual learning and memory has provided new tools and methods to undertake further research in this area. Such investigations could include: the effects of supplementation and training load on cognition, the relationship between cognition and injury prevalence, and the effects of novel interventions such as meditation on cognition and skill acquisition. Future research may also aim to establish a more reliable test for the assessment of executive function in rugby union players.
Chapter 3: The effects of brief mindfulness meditation on indices of cognitive function in trained rugby union players

Submitted for peer-review with Consciousness and Cognition (June, 2016)
3.1 Abstract

The purpose of this study was to determine the immediate effects of a mindfulness meditation session on cognitive performance in team-sport athletes. Male rugby union players were randomly assigned to two groups; the Mindful group and the Control group. Participants performed two trials of a computer-based cognitive test battery assessing domains of executive function (Groton maze learning task; GMLT), psychomotor function (Detection task; DET), vigilance (Identification task; IDN), visual learning and memory (One card learning task; OCL) separated by either a 20-min mindfulness meditation session (Mindful group) or quiet rest (Control group). The results revealed there were no significant effects of mindfulness meditation on any of the cognitive performance variables from the test battery. We concluded that a single session of mindfulness meditation had no immediate effect on cognitive performance in team-sport athletes. Further research is needed to investigate chronic effects of training interventions.
3.2 Introduction

Elite team-sport athletes possess the ability to: i. Attend to important environmental information, ii. Recognise and recall patterns of play, and iii. Make correct decisions during a game or match (Buszard et al., 2013; Roca et al., 2013). They are also required to execute repeated high-velocity manoeuvres, such as ‘side-stepping,’ to pass an opposing player, while maintaining speed and balance (Gabbett, Sheppard, Pritchard-Peschek, Leveritt, & Aldred, 2008; Sheppard, Young, Doyle, Sheppard, & Newton, 2006). Superior evasive strategies require fine neuromuscular control that relies on sensory information from proprioceptive, kinaesthetic, vestibular and visual input, as well as cortically programmed muscle pre-activation and reflex-mediated contractions (Forssberg & Nashner, 1982; Ghez & Krakauer, 1991; Taube et al., 2007). All of these motor patterns are planned and regulated by the cerebral cortex that highlights the important relationship between cognitive function and motor pattern execution in sport.

Current research in the area of cognitive function and sport performance includes the examination of ‘higher-order’ cognitive skills such as sport-specific decision making (Buszard et al., 2013; Farrow, Baker, & MacMahon, 2013; Lorains, Ball, & MacMahon, 2013), whereas basic cognitive skills such as vigilance, spatial memory, and executive function have traditionally been investigated for the purpose of assessing and monitoring recovery from concussion injury (Collie, Darby, & Maruff, 2001; A. Gardner, Shores, & Batchelor, 2010; Schatz, Pardini, Lovell, Collins, & Podell, 2006). Recent evidence suggests that fundamental cognitive ability may be a predictor of non-contact injury risk. Swanik et al. (2007) established that athletes who subsequently suffered non-contact anterior cruciate ligament (ACL) injuries had slower processing speeds and reaction times, as well as lower
memory scores when assessed during preseason testing compared to athletes who did not sustain and ACL injury. Deficits in basic cognitive function may compromise an athlete’s judgement, cause loss of coordination and place them at risk of injury. Therefore, it seems plausible to explore interventions with potential to increase basic cognitive function as they may help to reduce non-contact injury prevalence in team sports.

There is a growing interest in the efficacy of novel interventions for the purpose of improving cognition, such as interacting with nature (Berman, Jonides, & Kaplan, 2008), yoga (Gothe et al., 2013) and meditation (Hodgins & Adair, 2010; Kaul, Passafiume, Sargent, & O'Hara, 2010). Recently, the positive effects of mindfulness training (MT) have been highlighted in cognitive domains including sustained (Chambers et al., 2008; Jha et al., 2007), selective (Tang et al., 2007), and executive attention (Chan & Woollacott, 2007), working memory (Zeidan et al., 2010), and executive functions such as autobiographical memory, cognitive inhibition, and cognitive flexibility (Heeren et al., 2009). Baer (2003) previously described mindfulness as, “The non-judgmental observation of the ongoing stream of internal and external stimuli as they arise.” Therefore, if being mindful can improve cognitive performance in non-athletic population groups, the potential for an improvement in team-sport athletes is worth considering. Nevertheless, before we can recommend the implementation of MT into the training programs of team-sport athletes, we need to explore effective doses of MT and whether there are improvements in reliable and valid measures of cognitive performance after a single mindfulness meditation session. If an acute dose of mindfulness meditation evokes improvements in cognitive performance, this would be a useful tool for team-sport athletes to use before a game to reduce non-contact injury risk or to replace sleep debt obtained from travelling.
The purpose of the present study was to investigate the effect of a brief mindfulness meditation session on cognitive performance in team-sport athletes. Perceptual cognitive ability was analysed through the performance on a computer-based cognitive test battery containing tasks that test the cognitive domains of executive function, psychomotor function, vigilance, visual learning and memory.

3.3 Methods

3.3.1 Participants

Twenty male rugby union players were recruited for the current study. Participants were randomly assigned to two groups: 1. Mindful group (n = 10; age 18.6 ± 0.6 yr), and 2. Control group (n = 10; age 18.6 ± 0.5 yr), and had no prior experience in any style/form of meditation. All participants were considered highly trained, completing > 12 h·wk⁻¹ of training while playing for a state under 20’s representative rugby union team. All participants were informed of the study requirements and provided written informed consent. The study was conducted at the training grounds of the rugby union club and was approved by the Griffith University Human Research Ethics Committee.

3.3.2 Experimental design

Participants attended the rugby training grounds on two separate occasions. Day 1 and 2 were separated by > 24 h. Day 1 of testing consisted of familiarisation of the cognitive test battery for both groups. The Mindful group were also required to listen to a 5-min audio recording
that explained the origins of mindfulness and what they were to experience during the meditation session. On Day 2, participants completed two trials of the cognitive test battery. In between trials, the Mindful group completed a 20-min mindfulness meditation session while the Control group rested quietly for 20 min in an upright, seated position. Participants were asked to abstain from alcohol and caffeine for 24 h before Day 2 of testing.

3.3.3 Mindfulness meditation session

The 20-min mindfulness session was based upon a subgroup of meditation practices typically described as focused-attention meditation. During the mindfulness session, individuals in the Mindful group were seated comfortably in a chair with their back, neck, and head aligned to the vertical, maintaining relaxed shoulders, their hands resting comfortably on their thighs facing upward, and with their eyes closed. The primary focus of the mindfulness session was for participants to direct their attention to the ‘present breath,’ along with other present happenings such as the feeling of their feet against the floor, the sound of the inhalation breath, or the feeling of the tension in their muscles.

3.3.4 Cognitive test battery

During performance of both cognitive trials, participants were seated in an upright posture on the same chair and at the same desk. The test battery, CogState (CogState Ltd., Melbourne, VIC, Australia), was presented on a Lenovo T420 14’ Notebook (Core i5 processor, 2.5 gHz, Lenovo Group Ltd., Morrisville, USA) complete with headphones for audible cues and to eliminate audible distractions. All tests within the battery were adaptations of standard neuropsychological and experimental psychological tests. The battery required approximately
10 min to complete and consisted of four tests presented in succession. Written instructions were presented on the screen prior to beginning of each test along with an interactive demonstration. The three individual tests, in their order of presentation, were the Detection Task, the Identification Task, and the One Card Learning Task. The rationale, method of administration, and performance measures for each task has been described in detail elsewhere (MacDonald & Minahan, 2015).

The reliability of this CogState cognitive test battery has previously been established by MacDonald and Minahan (2015) at 30-min and 24-h retest intervals. The intraclass correlation coefficients for all performance variables ranged from 0.67 to 0.92 and 0.57 to 0.83 when comparing trials performed at 30-min and 24-h (respectively) retest intervals indicating acceptable to excellent intra- and inter-day reliability (Hopkins, 2000).

### 3.3.5 Data analysis

All dependent variables were analysed using fully-factorial ANOVA with repeated measures. Where statistically significant F values were detected, pairwise comparisons using Fisher’s least significant difference were performed to determine differences. Where statistical significance was observed between primary group variables, Cohen’s effect size (d) was calculated. IBM SPSS Statistics for Windows (Version 22.0, IBM Corp., Armonk, NY) was used for all statistical analyses. Statistical significance was accepted at \( p < 0.05 \).
3.4 Results

Mean group performance values for each cognitive test are presented in Table 3.1. There were a reduced number of total errors performed on the GMLT after mindfulness instruction ($F = 8.341, p = 0.01, 95\% \text{ CI} 1.91 – 12.09$). However, there was no difference in total errors made on the GMLT between the two groups, before or after the mindfulness session ($F = .147, p = 0.71, 95\% \text{ CI} -12.30 – 8.50$). There was no change in DET performance variables mean reaction time (RT; $F = 1.972, p = 0.18, 95\% \text{ CI} -21.53 – 4.28$), and 40% Fastest RT ($F = 0.458, p = 0.51, 95\% \text{ CI} -15.11 – 7.75$) in either of the groups when comparing pre and post cognitive performance trials. There were also no between-group differences in DET performance variables mean RT ($F = 0.077, p = 0.78, 95\% \text{ CI} -24.60 – 32.10$) and 40% Fastest RT ($F = 2.613, p = 0.12, 95\% \text{ CI} -4.15 – 31.83$) at pre and post conditions. A reduction in performance of the IDN was revealed in variables mean RT ($F = 18.626, p < 0.01, 95\% \text{ CI} -48.32 - -16.68$) and 40% fastest RT ($F = 10.504, p < 0.01, 95\% \text{ CI} -24.46 - -5.22$) in both groups when comparing pre and post cognitive performance trials. However, there were no between-group differences in IDN mean RT ($F = 0.507, p = 0.49, 95\% \text{ CI} -76.39 – 37.71$) and 40% Fastest RT ($F = 0.354, p = 0.56, 95\% \text{ CI} -47.12 – 26.33$) before or after the mindfulness session. Finally, there was no change in OCL accuracy ($F = 0.541, p = 0.47, 95\% \text{ CI} -0.03 – 0.05$) and mean RT ($F = 0.347, p = 0.56, 95\% \text{ CI} -21.63 – 38.49$) when comparing pre and post cognitive trial performance in both groups. There were also no between-group differences in OCL accuracy ($F = 3.161, p = 0.09, 95\% \text{ CI} -0.01 – 0.16$) and mean speed ($F = 0.037, p = 0.85, 95\% \text{ CI} -137.46 – 114.31$) at pre and post conditions.
Table 3.1. Group mean performance values from the cognitive test battery performed before and after a single 20-min mindfulness meditation session (Mindful group) or quiet rest (Control group).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mindful group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GMLT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total errors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>40.1 ± 12.8</td>
<td>42.4 ± 15.0</td>
</tr>
<tr>
<td>Post</td>
<td>*33.5 ± 10.6</td>
<td>*35.0 ± 10.3</td>
</tr>
<tr>
<td><strong>DET</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>301.44 ± 26.43</td>
<td>302.09 ± 28.59</td>
</tr>
<tr>
<td>40% Fastest RT (ms)</td>
<td>264.73 ± 17.06</td>
<td>257.20 ± 16.27</td>
</tr>
<tr>
<td>IDN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>437.61 ± 51.60</td>
<td>463.60 ± 63.45</td>
</tr>
<tr>
<td>40% Fastest RT (ms)</td>
<td>378.43 ± 35.87</td>
<td>393.60 ± 42.98</td>
</tr>
<tr>
<td>OCL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>81.19 ± 9.30</td>
<td>72.19 ± 9.57</td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>832.10 ± 118.15</td>
<td>841.15 ± 151.12</td>
</tr>
</tbody>
</table>

Note. GMLT = Groton Maze Learning Task. DET = Detection Task. RT = reaction time. IDN = Identification Task. OCL = One Card Learning Task. * = p < 0.01. ** = p < 0.001.

3.5 Discussion

The primary finding of the present study was that a single session of mindfulness meditation does not improve performance on a computer-based cognitive test battery in young, highly-trained rugby union players. Any change in performance of a cognitive test in the Mindful group was mimicked by the Control group. These results indicate that: 1. Any influence of mindfulness instruction on cognitive function was not different to quiet rest, 2. A larger dose (e.g., longer or more frequent mindfulness meditation sessions) may have been required to evoke improvements in cognitive performance in the rugby union players, or 3. The battery of cognitive-tasks was not sensitive enough to highlight any changes in cognitive function.

Performance of the GMLT improved from the pre to post conditions with a reduction in total
errors in both groups. This indicates that any positive influences obtained from the mindfulness session were no different to those elicited by quiet rest. However there were no changes in performance of the DET and the OCL, in both groups, when comparing cognitive trials performed before and after the intervention. Furthermore, a reduction in performance of the IDN was revealed, in both groups, following the mindfulness session (Mindful group) and quiet rest (Control group). Therefore, it seems plausible that improvements in GMLT performance resulted from a learning effect experienced by participants across cognitive trials. In addition, the reduction in performance of the IDN may be explained by the phenomena of mental fatigue (Boksem & Tops, 2008), however further research would be necessary to determine this. Nevertheless, the evidence suggests that any changes in performance of the computer-based cognitive test battery were not a product of the 20-min mindfulness meditation.

A similar study, using alternate meditation techniques, has previously been conducted by Kaul et al. (2010) in ten university students. They examined performance on the Psychomotor Vigilance Test (PVT) before, immediately after and 1 h after four different treatments: 1. A 40-min concentrative (similar to mindfulness) meditation session, 2. The same meditation session preceded by 32 h of sleep deprivation, 3. A 40-min nap and 4. Quiet rest. The results showed a significant improvement in mean RT on the PVT immediately following the meditation session (~20 ms change, \( p < 0.01 \)), and meditation following sleep debt (~30 ms change, \( p < 0.01 \)). It was reported that PVT mean RT returned to baseline performance (pre-treatment) when performed 1 h later. Kaul et al. (2010) concluded that a single concentrative meditation session may serve as a performance-enhancing and restorative treatment for novice meditators. However, in the present study, the meditation session did not affect any of the cognitive performance measures in the rugby union players.
It is possible that the mindfulness meditation session in the present study was not long enough to elicit a change in performance results on the cognitive tests. The study by Kaul et al. (2010) employed a 40-min session, whereas the session chosen for the present study was of much shorter duration (20 min). It is unclear as to the appropriate or minimum length of time one should meditate for to achieve a state of mindfulness. According to Siegel (2009), the amount of time spent meditating is dependent upon the individual. However, Siegel (2009) also reports that such practices are generally dose-related, meaning that if more time is dedicated to a mindfulness session, the more profound the effects will likely be. Therefore, it is possible that a longer mindfulness session (i.e., 40 min) may have evoked improvements in cognitive performance in the rugby union players. Nevertheless, we chose a 20-min session as it may be more suitable for coaches and players in occasions with time constraints such as before a game or during a heavy training schedule.

To ensure complete naivety to the mindfulness meditation, the only introduction provided to the rugby union players was a 5-min audio recording. The first and only meditation session completed was during actual testing. The university students in the study by Kaul et al. (2010) completed two, 1-h instructed meditation sessions as familiarisation before completing another two, 40-min sessions in two of the four conditions that were investigated. It is therefore reasonable to assume the protocol employed by Kaul et al. (2010) was, in fact, a three or four-session meditation intervention (with respect to the order that the conditions were assessed) and that if repeated sessions were employed in the present study may have cognitive performance improvements may have ensued. Zeidan et al. (2010) implemented a 4-d (20 min·d⁻¹) MT intervention in twenty-four university students. When compared to controls, significant improvements were revealed in the meditating group on performance of
The Symbol Digit Modalities Test \((p = 0.01)\), The Controlled Oral Word Association Test \((p = 0.03)\), and The N-Back Task \((p = 0.01)\). It is difficult to assume similar results would have occurred in the present study had a similar protocol been implemented in the rugby union players. Nevertheless, the purpose of the present study was to investigate whether a single-dose of mindfulness meditation can immediately improve cognitive performance in a sporting population.

The type of the meditation may also explain the conflicting results of the present study from those of Kaul et al. (2010). The objective of concentrative meditation, practised in the study by Kaul et al. (2010), is to cultivate a single-pointed attention on an object (i.e., a sound, an image, or a flame etc.). It has been reported that, through concentrative meditation, the mind develops a capacity to remain calm, stabilized, and grounded (Broww, 1977). Mindfulness meditation is similar to that of concentrative meditation in that it also has an object as the focal point (i.e., the present breath, present noises, sensations etc.) However the focus of mindfulness practices is not as narrow as concentrative meditation, as it is a combination of concentration and open awareness, meaning that one must maintain a simultaneous awareness of other phenomena (Brown & Ryan, 2003). It has previously been suggested that mindfulness meditation can be challenging as a novice meditator (Kabat-Zinn, 2011). Therefore, participants may have found it difficult to meditate, in the present study, which showed in the unchanged performance on the cognitive test battery. Conversely, concentrative meditation may be easier to practise as a novice that would mean the university students were able to achieve a ‘meditative state’ leading to improved PVT performance.

Finally, the CogState cognitive test battery may not have been sensitive enough to reveal improvements elicited by the mindfulness meditation session. No other study has
implemented the CogState test battery, as a measure of cognitive performance, to investigate the effects of a mindfulness meditation session. Previous studies have shown the positive influences of MT on the performance of numerous tests assessing various different cognitive domains including sustained (Chambers et al., 2008; A. P. Jha et al., 2007), selective (Tang et al., 2007), and executive attention (Chan & Woollacott, 2007), working memory (Zeidan et al., 2010), and executive functions such as autobiographical memory, cognitive inhibition, and cognitive flexibility (Heeren et al., 2009). However, all of these studies employed interventions containing multiple meditation sessions making it difficult to draw comparisons with the findings of the present study.

It is worth that sample size may be seen as a limitation in the present study. A larger sample size may have resulted in a different outcome, as power estimates for the dependent variables ranged from 0.30 – 0.97. However, due to the nature of elite sport, low sample sizes are often observed in sporting research (Secomb, Nimphius, Farley, Lundgren, Tran & Sheppard, 2016; Veness, Patterson, Jeffries & Waldron, 2017). Nonetheless, despite the low statistical power, Biau, Kerneis and Porcher (2008) have highlighted the importance of identifying what can be considered a ‘meaningful’ change in the dependent variable. In addition, Hopkins (2004) has reported that, in elite sport, athletes and coaches would be ‘reasonably confident of a worthwhile change’ where an increase in half the typical error of the dependent variable is observed. Hopkins (2004) also recommends that athletes should aim to improve by double the typical error of the dependent variable. A study by MacDonald and Minahan (2016) demonstrated what would be considered a ‘worthwhile change’ in performance of the CogState test battery. For example, given the typical error of 4.2% for mean speed on the Detection Task, coaches and athletes would be ‘reasonably confident of a worthwhile change’ (Hopkins, 2004) where an increase in mean speed of 2.1% (i.e., half the typical error)
or 6 ms is observed. In addition, athletes should aim to improve by double the typical error (Hopkins 2004; i.e., 8.4% for mean speed), or 25 ms, from an initial mean speed of 294 ms. Considering the recommendations made by Hopkins (2014) and the findings of MacDonald and Minahan (2016), any observed improvements in the cognitive performance variables in the Mindful group, that were not also observed in the Control group, were not great enough to be considered a ‘worthwhile change.’ Therefore, it is reasonable to suggest that the mindfulness meditation session had no significant effect on cognitive performance in the rugby union players.

The present study did not observe an improvement in performance of a cognitive test battery after a single 20-min mindfulness meditation session in a team of rugby union players. It is well researched that MT improves cognitive processing in both clinical and healthy populations. Further research is warranted to determine an appropriate and effective mindfulness session length that will evoke changes in cognitive performance. Future research could also be directed at implementing a MT intervention in a sporting population to evaluate its long-term effects on determinants of cognition, as well as sporting performance.
Chapter 4: The effects of mindfulness meditation training on indices of cognitive function in rugby union players

Submitted for peer-review with the Journal of Sports Sciences (January, 2016)
4.1 Abstract

The purpose of this study was to determine the effect of a 4-wk mindfulness meditation training intervention on indices of basic cognitive function in a team of trained rugby union players (Mindful group, n = 8; Control group, n = 8). The Mindful group performed three, 20-min mindfulness meditation sessions each week during the intervention. Cognitive function was assessed by performing trials of a computer-based cognitive test battery assessing domains of psychomotor function (Detection task; DET), vigilance (Identification task; IDN), visual learning and memory (One card learning task; OCL). Cognitive function was assessed at baseline (0 wk), mid-intervention (2 wk), and follow-up (4 wk). There was no mean improvement in any of the tests of cognitive function throughout the 4-wk of mindfulness meditation training ($p > 0.05$). It was concluded that an intervention of three, 20-min sessions per week, for four weeks does not improve cognitive function in a team rugby union players. Further research is necessary to determine optimal dosage and other aspects of sports performance that may be positively affected by mindfulness training.
4.2 Introduction

Our curiosity with cognitive function in elite team-sport performance is manifested when sports commentators and coaches often refer to an athlete’s ability to ‘stay alert’ or to ‘read the play.’ Repeated high-velocity movements such as ‘side-stepping’ to pass an opposing player require fine neuromuscular control that is contingent on sensory information from proprioceptive, kinaesthetic, vestibular and visual input, as well as cortically programmed muscle pre-activation and reflex-mediated contractions (Ghez & Krakauer, 1991; Sheppard et al., 2006). Ultimately, the cerebral cortex is responsible for the planning and regulation of all such motor patterns (Taube et al., 2007), highlighting the important relationship between cognition and motor pattern performance in sport.

Fundamental cognitive skills such as reaction time, spatial memory and executive function have traditionally been investigated for the purpose of assessing and monitoring recovery from concussion injury (Collie et al., 2001; Schatz et al., 2006). Furthermore, recent evidence suggests that basic cognitive function may be a predictor of non-contact injury risk. Swanik et al. (2007) demonstrated that collegiate athletes who subsequently suffered non-contact anterior cruciate ligament injuries had slower reaction times and processing speeds, as well as lower visual and verbal memory scores when measured during preseason testing compared to athletes who did not sustain an ACL injury during the season. Deficits or lapses in cognitive function could increase an athlete’s susceptibility to brief errors in judgement or loss of coordination when confronted with complex environmental cues during gameplay (Lajoie, Teasdale, Bard, & Fleury, 1993). Therefore, interventions that have the potential to improve basic cognitive function could be useful in helping to reduce non-contact injuries in team-sport athletes.
Researchers have employed various types of interventions in the attempt to improve cognition, such as exercise (Lambourne & Tomporowski, 2010) and caffeine supplementation (Foskett, Ali, & Gant, 2009). There is also growing emphasis on more novel approaches to improving cognition such as yoga (Gothe et al., 2013) and meditation (Hodgins & Adair, 2010). The use of mindfulness training (MT) and the positive effects it has on cognition has been demonstrated in healthy populations (Jha et al., 2007), hyperactive (Zylowska et al., 2008) and mood disorders (Williams, Teasdale, Segal, & Soulsby, 2000). Athlete-focused MT interventions have also been developed to increase sports performance. Gardner and Moore’s (2004) mindfulness-acceptance-commitment (MAC) approach, as well as Kaufman’s (2009) Mindful Sport Performance Enhancement (MSPE) program have been implemented with an adolescent springboard diver (Schwanhausser, 2009), long distance runners, golfers and archers (Thompson, Kaufman, De Petrillo, Glass, & Arnkoff, 2011). Indeed, these studies reported enhancements in subjective ratings of experiential acceptance, dispositional flow, and mindfulness attention (Schwanhausser, 2009), as well as increases in national ranking and longitudinal improvements in running time (Thompson et al., 2011). However these studies are lacking in measures of objectivity and their conclusions as to how MT has improved sporting performance seem implausible. Importantly, none of these studies have analysed the effects of MT on cognitive function.

The purpose of the present study was to examine the effects of 4 wk of MT on indices of cognitive function in a rugby union team. The particular cognitive domains of interest are psychomotor function, vigilance, visual learning and memory.
4.3 Methods

4.3.1 Participants

Sixteen male rugby union players were recruited for the current study. All participants were free from, or had not suffered a concussion in the 12 months prior to the study. Participants were randomly assigned to two groups: The Mindful group \((n = 8; \text{age: } 18.8 \pm 0.5 \, \text{yr})\) and the Control group \((n = 8; \text{age: } 18.6 \pm 0.5 \, \text{yr})\), and had no prior experience in any style of meditation. All participants were considered highly-trained, completing \(>12 \, \text{h\,wk}^{-1}\) of training while playing for a state under 20’s representative rugby union team. All participants were informed of the study requirements and provided written informed consent. The study was conducted at the training grounds of the rugby union club and was approved by the Griffith University Human Research Ethics Committee.

4.3.2 Experimental design

Participants were required for a familiarisation session, a 4-wk training period, and a follow-up testing session to complete the present study. During the familiarisation session, all participants were familiarised on the cognitive test battery and the Mindful group listened to a 5-min recording that explained the origins of mindfulness and what they were to experience during the meditation session. During the 4-wk MT period, the Mindful group were required three times each week, on alternate days (i.e., Monday, Wednesday, and Friday) to complete a 20-min mindfulness meditation session. On the first day of weeks 1 and 3 of the MT period, both the Mindful group and the Control group completed two trials of the cognitive test
battery. In between trials, the Mindful group completed a 20-min mindfulness session while the Control group rested quietly for 20 min in an upright, seated position. The follow-up testing session was completed two days after the conclusion of the training period where the Mindful group completed two trials of the cognitive test battery, separated by 20-min mindfulness meditation. The Control group also completed two trials of the cognitive test battery, separated by 20-min quiet rest. All sessions containing cognitive testing were completed at the same time of day.

4.3.2 Mindfulness training

During the 20-min mindfulness meditation session, participants listened to a recorded instruction based upon a subgroup of meditation practices typically described as concentrative or ‘focused’ attention meditation. Participants were seated comfortably in a chair with their back, neck, and head aligned to the vertical, maintaining relaxed shoulders, their hands resting comfortably on their thighs facing upward, and with their eyes closed. The primary focus of the mindfulness session was for participants to direct their attention to the ‘present breath,’ along with other present happenings such as the feeling of their feet against the floor, the sound of the inhalation breath, or the feeling of the tension in their muscles.

4.3.3 Cognitive test battery

During performance of each cognitive trial, participants were seated in an upright posture on the same chair and at the same desk. The test battery, CogState (CogState Ltd., Melbourne, VIC, Australia), was presented on a Lenovo T420 14’ Notebook (Core i5 processor, 2.5 gHz, Lenovo Group Ltd., Morrisville, USA) complete with headphones for audible cues and to
eliminate audible distractions. All tests within the battery were adaptations of standard neuropsychological and experimental psychological tests. The battery required approximately 10 min to complete and consisted of four tests presented in succession. Written instructions were presented on the screen prior to beginning of each test along with an interactive demonstration. The three individual tests, in their order of presentation, were the Detection Task, the Identification Task, and the One Card Learning Task. The rationale, method of administration, and performance measures for each task has been described in detail elsewhere (MacDonald & Minahan, 2015).

The reliability of these cognitive tests has previously been established by MacDonald and Minahan (2015) at 30-min and 24-h retest intervals. The intraclass correlation coefficients for all performance variables ranged from 0.75 to 0.92 and 0.70 to 0.83 when comparing trials performed at 30-min and 24-hr (respectively) retest intervals indicating acceptable to excellent intra- and inter-day reliability (Hopkins, 2000).

4.3.4 Data analysis

The acute effects were analysed separately at three time points: i. Baseline (BL; 0 wk), ii. Mid-intervention (MI; 2 wk) and, iii. Follow-up (FU; 5 wk), by comparing cognitive performance before and after the intervention (meditation vs quiet rest) from both groups. Chronic effects were also analysed by comparing the ‘pre’ conditions from the three time points. Analyses were completed using a fully-factorial ANOVA with repeated measures. Where statistically significant F values are detected, pair-wise comparisons using Fisher’s least significant difference were performed to determine differences. Where statistical significance was observed between primary group variables, Cohen’s effect size (d) was
calculated. IBM SPSS Statistics for Windows (Version 22.0, IBM Corp., Armonk, NY) was used for all statistical analyses. Statistical significance was accepted at \( p < 0.05 \).

### 4.4 Results

The primary and secondary group performance variables for each cognitive test, performed before and after the intervention (meditation vs quiet rest), at BL, MI and FU are presented in Figure 4.1 and Table 4.1, respectively.

**Psychomotor function (DET)** There was no significant interaction among the three independent variables: i. Time (i.e., across the 4-wk of training), ii. Pre/post (i.e., before and after an acute session of mindfulness meditation), and iii. Group (i.e., Mindful group vs Control group); \( F = 2.177, p = 0.13 \) for DET mean reaction time (RT). Furthermore, there was no main effect of time (\( F = 0.372, p = 0.69 \)) or group (\( F = 0.461, p = 0.51, 95\% \text{ CI } -24.60 \text{ to } 12.77 \)). However, DET mean RT was lower after compared to before acute mindfulness meditation or quiet rest (\( F = 7.779, p = 0.01, 95\% \text{ CI } -16.65 \text{ to } -2.17 \)). There was no significant interaction among independent variables for DET 20% or 40% Fastest RT (\( F = 1.026, p = 0.37; F = 0.643, p = 0.53 \), respectively) and no main effect of MT (\( F = 1.685, p = 0.20; F = 1.085, p = 0.35 \)) or group (\( F = 4.283, p = 0.06, 95\% \text{ CI } -0.47 \text{ to } 26.39; F = 3.232, p = 0.09, 95\% \text{ CI } -2.11 \text{ to } 24.00 \)). Acute mindfulness meditation or quiet rest did not affect the DET 20% or 40% Fastest RT values (\( F = 0.966, p = 0.34, 95\% \text{ CI } -12.54 \text{ to } -4.66; F = 0.919, p = 0.35, 95\% \text{ CI } -11.35 \text{ to } -4.34 \)).

**Vigilance (IDN)** No significant interaction was revealed among the independent variables of time, pre/post, and group for IDN mean RT (\( F = 0.279, p = 0.76 \)). Additionally, 4 wk of MT
did not change IDN mean RT ($F = 0.699, p = 0.50$) and there were no differences in IDN mean RT between the groups ($F = 1.716, p = 0.21, 95\% \text{ CI} -62.49 - 15.10$). Nonetheless, IDN mean RT slowed after compared to before mindfulness meditation or quiet rest ($F = 5.704, p = 0.03, 95\% \text{ CI} -19.73 - -1.06$). Similar results were found for the IDN 20 and 40% Fastest RT values. The ANOVA indicated no interaction between the independent variables ($F = 0.965, p = 0.39; F = 0.181, p = 0.83$, respectively) and no main effects for time ($F = 1.274, p = 0.29; F = 1.323, p = 0.28$, respectively) or group ($F = 0.248, p = 0.63, 95\% \text{ CI} -28.47 - 17.73; F = 0.517, p = 0.48, 95\% \text{ CI} -32.53 - 16.20$, respectively). However, mindfulness meditation or quiet rest did result in a decrease in both the IDN 20% and 40% Fastest RT values ($F = 6.262, p = 0.03, 95\% \text{ CI} -18.17 - 1.40; F = 6.337, p = 0.03, 95\% \text{ CI} -18.20 - -1.45$, respectively).

**Visual learning and memory (OCL)** OCL accuracy and mean speed did not change after 4 wk of MT ($F = 1.325, p = 0.28; F = 0.251, p = 0.78$, respectively) and acute mindfulness meditation or quiet rest did not alter the OCL accuracy and mean RT values ($F = 0.329, p = 0.58, 95\% \text{ CI} -3.40 - 2.00; F = 4.423, p = 0.05, 95\% \text{ CI} -0.45 - 46.19$). Furthermore, OCL accuracy and mean RT was not different between the Mindful group and the Control group at any time during the 4-wk training period ($F = 2.828, p = 0.12, 95\% \text{ CI} 72.5 - 86.2; F = 0.224, p = 0.64, 95\% \text{ CI} -93.49 - 146.48$, respectively).
Figure 4.1. Group primary performance variables for A. The Detection Task, B. The Identification Task, and C. The One Card Learning Task, performed before and after meditation (Mindful group) or quiet rest (Control group) at baseline, mid-intervention and follow-up.
Table 4.1. Group secondary performance variables for each cognitive test, performed before and after meditation (Mindful group) or quiet rest (Control group), at baseline, mid-intervention, and follow-up.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Baseline</th>
<th>Meditators</th>
<th>Controls</th>
<th>Mid-intervention</th>
<th>Meditators</th>
<th>Controls</th>
<th>Follow-up</th>
<th>Meditators</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>DET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>20% Fastest RT</td>
<td>248.8 (18.4)</td>
<td>257.6 (16.1)</td>
<td>241.3 (15)</td>
<td>230.5 (27.4)</td>
<td>245.7 (24.5)</td>
<td>259.4 (9.3)</td>
<td>237.6 (18.5)</td>
<td>240.5 (21.6)</td>
<td>252.3 (10.9)</td>
</tr>
<tr>
<td>40% Fastest RT</td>
<td>261.1 (16.9)</td>
<td>268.5 (17.3)</td>
<td>253.9 (16.4)</td>
<td>245.7 (22)</td>
<td>258.2 (19.4)</td>
<td>271.4 (8.6)</td>
<td>251.8 (16.1)</td>
<td>254.1 (11.9)</td>
<td>262.8 (11.4)</td>
</tr>
<tr>
<td>IDN</td>
<td></td>
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<tr>
<td>20% Fastest RT</td>
<td>350 (28.4)</td>
<td>370.2 (30.8)</td>
<td>367.7 (40)</td>
<td>366.7 (31)</td>
<td>365.3 (24.5)</td>
<td>372.4 (23)</td>
<td>365.7 (21.6)</td>
<td>378.4 (34)</td>
<td>354.3 (21.3)</td>
</tr>
<tr>
<td>40% Fastest RT</td>
<td>369.9 (27.4)</td>
<td>389.1 (30.3)</td>
<td>388.1 (45.1)</td>
<td>394.6 (34.1)</td>
<td>388 (22.8)</td>
<td>396.2 (26.8)</td>
<td>394.1 (23.8)</td>
<td>399.1 (40.3)</td>
<td>376.3 (25.4)</td>
</tr>
<tr>
<td>OCL</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mean RT (ms)</td>
<td>805.2 (81.2)</td>
<td>791.3 (93.5)</td>
<td>843.7 (168.7)</td>
<td>832 (184.2)</td>
<td>854 (90.6)</td>
<td>808.3 (88.2)</td>
<td>804.8 (111.2)</td>
<td>789.4 (94.9)</td>
<td>849.1 (150.8)</td>
</tr>
</tbody>
</table>

Note. DET = Detection Task. RT = reaction time. IDN = Identification Task. OCL = One Card Learning Task. IDN 20% and 40% Fastest RT slowed after compared to before meditation or quiet rest (F = 6.262, p = 0.03; F = 6.337, p = 0.03, respectively).
4.5 Discussion

The present study examined the effects of 4 wk of MT on determinants of cognition in rugby union players. Acute (pre vs post a single session) and chronic (training) effects were analysed at three different time points (baseline, mid-intervention and follow-up) throughout the testing period via performance of a cognitive test battery that assessed the domains of psychomotor function, vigilance, visual learning and memory. Although there were no acute changes following the first mediation session, it was thought that MT might provoke an acute effect following a meditation session at MI or FU. However, the MT did not acutely, nor chronically, improve cognitive function in the rugby union players.

Before a training program is implemented as an intervention, there are numerous factors that must be considered that will contribute to the findings of the research. Certain elements such as athlete compliance, minimalizing measurement error, and dosage consideration are essential to the potential success of a training intervention such as mindfulness meditation. In the present study, athlete compliance was safeguarded as participants completed every intervention session (i.e., mindfulness meditation) under supervision of the Chief Investigator at the training grounds of their Rugby Union club. Measurement error was also minimised as all cognitive test trials were delivered by the Chief Investigator under the same conditions (i.e., same time of day, location etc.). The intervention was chosen as it could be implemented into the sporting group without hindering the current individual as well as team training and coaching procedures.
It is possible that the dose of MT (three, 20-min sessions each week for four weeks) was not substantial enough to evoke an improvement in cognitive function in the rugby union players. However, similar studies have been conducted in clinical and healthy populations, with interventions of varying length and frequency, revealing positive influences of MT on cognitive performance (Chiesa et al., 2011). Moreover, very brief MT interventions have also improved cognitive performance. Tang et al. (2007) implemented a 5-d, 20-min/day intervention in forty university students and showed a significant increase in executive attention scores on the Attention Network Test. Additionally, Kaul et al. (2010) revealed acute improvements in psychomotor vigilance following a single, 40-min meditation session in ten university students. To our knowledge, this is the first study to analyse the effects of MT on indices of cognition in a sporting population. Therefore, it is difficult to determine whether MT will evoke improvements specifically in performance of a cognitive test battery.

It is also possible that the cognitive test battery was not sensitive enough to highlight potential changes in cognitive function evoked by MT. The cognitive tests in the present study have been designed to measure fundamental cognitive skills. Though, similar cognitive tests have been criticized for their lack of ecological validity (Ali, 2011) and there is conflicting evidence concerning their ability to differentiate competition level in athlete groups (Castiello & Umiltà, 1992; Helsen & Starkes, 1999). However, a meta-analysis by Voss et al. (2010) has highlighted the relevance of such tests as having “important implications for capturing and characterising the fundamental cognitive skills associated with competitive sport training.” Previous studies have implemented sport-specific cognitive tests that present sport-specific images (McMorris & Graydon, 1996), models (McMorris & Graydon, 1997), or
videos (Williams & Davids, 1998) to simulate gameplay situations for the assessment of decision-making ability and visual behaviours. Such tests are aimed at analysing the interaction directly between an athlete and their sporting environment, and their ability to differentiate expert and novice athletes has been established (Helsen & Starkes, 1999; Williams & Davids, 1998). It is unknown whether a sport-specific cognitive test would have highlighted potential changes elicited by the MT in the present study. Nevertheless, the cognitive tests in the present study were chosen due to their established retest reliability, whereas, the reliability of sport-specific cognitive tests is questionable due to sample heterogeneity (Atkinson & Nevill, 1998), potential habituation, and/or performance being determined by subjective opinion (Ali, 2011).

Although the present study showed no effects on cognitive function, previous researchers have managed to highlight the positive influences of MT on other determinants of performance. Gardner and Moore (2004) established the Mindfulness-Acceptance-Commitment (MAC) approach, consisting of twelve, 1-h weekly sessions, specifically designed for athletes to cultivate mindfulness, acceptance and self-regulation attention skills. Performance enhancements have been reported in an adolescent spring-board diver (Schwanhausser, 2009), golfers (Bernier, Thienot, Cordon, & Fournier, 2009), and a female power lifter (Gardner & Moore, 2004). More recently, Kaufman et al. (2009) developed and implemented the Mindful Sport Performance Enhancement (MSPE), a 2.5-h per wk, 4-wk program, in eleven archers. Reductions in scores of somatic anxiety (pre: 12.17, post: 10.67, \( p < 0.05 \)), thought disruption (pre: 49.71, post: 46.71, \( p < 0.05 \)), and increases in dispositional optimism (pre: 19.43, post: 21.14, \( p < 0.05 \)) and mindfulness (pre: 129.71, post: 138.57, \( p < 0.01 \)) ensued following the program. Thompson et al. (2011) also applied
the MSPE program in twenty-five long-distance runners, resulting in decreased feelings of worry (pre: 15.57, post: 13.09, $p < 0.05$) and increased awareness (pre: 25.10, post: 28.30, $p < 0.05$). Another study by John et al. (2011) identified the positive effect of ‘Mindfulness Meditation Therapy’ (MMT) on salivary cortisol in elite shooters. The MMT consisted of participants completing six, 20-min meditation sessions per week for four weeks. Salivary cortisol levels significant decreased (pre: 1.33 mg·L$^{-1}$, post: 0.66 mg·L$^{-1}$, $F = 834.6$, $p < 0.01$) in the elite shooters following the MMT. The MAC, MSPE and MMT programs have been effective in the studies discussed. However, they are time-demanding in intervention length (MAC), session duration (MSPE) or session frequency (MMT) and may be problematic in a team-sport environment. The intervention chosen for the present study was easy to implement due to short meditation sessions (20-min) and manageable frequency (3/wk). A recent study by Baltzell and Akhtar (2012) investigated the impact of a mindfulness training intervention, of similar duration, on nineteen female soccer players. Participants completed the ‘Mindfulness Meditation Training for Sport’ (MMTS) program, consisting of two, 30-min sessions per week for 6 weeks. The results showed significant increases in mindfulness scores ($p < 0.01$) after completion of the MMTS program. It is difficult to determine whether improvements in cognitive performance may have occurred in the study by Baltzell and Akhtar (2012), had a cognitive test battery been chosen as the dependent factor. Nevertheless, considering the research discussed, perhaps the positive influences of MT only manifest on performance determinants other than cognitive function, such as self-reported feelings and hormonal measures. However, further research would be necessary to determine this.
It is worth noting that the sample size in the present study may be seen as a possible limitation. A larger sample size may have resulted in a different outcome, as power estimates for the dependent variables ranged from 0.30 – 0.50. However, due to the nature of elite sport, low sample sizes are often observed in sporting research (Secomb et al., 2016; Veness et al., 2017). Nonetheless, despite the low statistical power, Biau, Kerneis and Porcher (2008) have highlighted the importance of identifying what can be considered a ‘meaningful’ change in the dependent variable. In addition, Hopkins (2004) has reported that, in elite sport, athletes and coaches would be ‘reasonably confident of a worthwhile change’ where an increase in half the typical error of the dependent variable is observed. Hopkins (2004) also recommends that athletes should aim to improve by double the typical error of the dependent variable. A study by MacDonald and Minahan (2016) demonstrated what would be considered a ‘worthwhile change’ in performance of the CogState test battery. For example, given the typical error of 4.2% for mean speed on the Detection Task, coaches and athletes would be ‘reasonably confident of a worthwhile change’ (Hopkins, 2004) where an increase in mean speed of 2.1% (i.e., half the typical error) or 6 ms is observed. In addition, athletes should aim to improve by double the typical error (Hopkins 2004; i.e., 8.4% for mean speed), or 25 ms, from an initial mean speed of 294 ms. Considering the recommendations made by Hopkins (2014) and the findings of MacDonald and Minahan (2016), any observed improvements in the cognitive performance variables in the Mindful group, that were not also observed in the Control group, were not great enough to be considered a ‘worthwhile change.’ Therefore, it is reasonable to suggest that the MT intervention had no significant effect on cognitive performance in the rugby union players.
The present study demonstrated that a MT intervention of three, 20-min sessions per week, for four weeks did not improve cognitive function in rugby union players. There is empirical evidence that interventions of varying length, duration and frequency elicit positive effects on subjective psychological feelings and hormonal measures in sporting populations. Future investigations could focus on identifying other aspects of sports performance that may be positively affected by MT. Further research is warranted in developing a standardised intervention that can be implemented in both team and individual sporting disciplines.
Chapter 5: Reliability of salivary cortisol and Immunoglobulin-A measurements from the IPRO® before and after sprint cycling exercise

Accepted for publication with the Journal of Sports Medicine and Physical Fitness (November, 2016)
5.1 Abstract

The purpose of this study was to evaluate the inter-day reliability of the IPRO method for determining resting and post-exercise salivary cortisol (sCort) and rate of salivary Immunoglobulin-A (sIgA) secretion. Fourteen males (31.9 ± 10.7 yr) performed two trials (T1 and T2) separated by 7 d, comprising saliva sampling before and 15 min after completion of two, 30-s Wingate Anaerobic Tests separated by 3.5 min (2 x WAnT). sCort increased after the 2 x WAnT in both trials (T1: \( p < 0.01 \); T2: \( p < 0.01 \)), whereas rate of sIgA secretion decreased in both trials (T1: \( p < 0.01 \); T2: \( p < 0.01 \)). The intraclass correlation coefficients for resting and post-exercise sCort and rate of sIgA secretion ranged from 0.96-0.99. Mean reliability, expressed as the coefficient of variation (%) and the typical error of measurement over the two trials were resting sCort 9.4%, 0.14 ng·mL\(^{-1}\) (95% CL 0.1-0.2), post-exercise sCort 11.9%, 0.44 ng·mL\(^{-1}\) (95% CL 0.3-0.7), resting rate of sIgA secretion 7.4%, 85.5 µg·mL\(^{-1}\)·min\(^{-1}\) (95% CL 65.2-127.1) and post-exercise rate of sIgA secretion 10.5%, 82.9 µg·mL\(^{-1}\)·min\(^{-1}\) (95% CL 63.2-123.1). It was concluded that the IPRO is a reliable method for determining sCort and rate of sIgA secretion at rest and after sprint-cycling exercise.
5.2 Introduction

Cortisol is a catabolic hormone secreted in response to psychophysiological stress and plays an integral role in energy mobilization, suppression of immune and reproductive function as well as inhibition of bone and muscle growth (Erickson et al., 2003; Thomas et al., 2009). Hackney, Premo, and McMurray (1995) demonstrated that cortisol concentration increased in response to long-duration cycling, while others have demonstrated an acute increase in cortisol concentration after supramaximal cycling exercise (Davies & Few, 1973; Paccotti et al., 2005; Thomas et al., 2009). Indeed, cortisol measurement in serum and plasma has previously been used to assess overreaching and overtraining syndrome in athletes (Duclos et al., 2007). Laudat et al., 1988 demonstrated that salivary cortisol concentration (sCort) has been shown to closely reflect the biological activity of the catabolic hormone in vivo. Due to convenience and non-invasiveness of sampling saliva and the usefulness of sCort to represent changes in acute and chronic physiological and psychological stress, sCort is among the most commonly assayed biomarkers in athletes.

Secretory Immunoglobulin-A forms the first line of immunological defence against colonization of infection by neutralizing and preventing viral pathogens from entering the body via the mucosal surfaces (Libicz et al., 2006; Tomasi & Plaut, 1985). Exercise also poses an integral challenge to mucosal immune function as determined by the changes observed in salivary immunoglobulin-A (sIgA; Papacosta & Nassis, 2011). Prolonged, high-intensity training and competition can attenuate sIgA (Libicz et al., 2006; Nieman et al., 2002) whereas sIgA has been shown to either increase (Tharp, 1991) or decrease (Fahlman et al., 2001) after a single bout of exercise.
Accordingly, sIgA measurement provides a valuable biomarker of training stress and immune function response. Indeed, it is thought that sIgA may provide insight into the incidence of upper-respiratory tract infection in athletes (Gleeson et al., 2012; Gleeson et al., 1999).

Traditionally, salivary analysis in athletic populations has been conducted using bio-sensory immunoassays allowing sports scientists to collect rapid, non-invasive measures of biological analytes in the field. Enzyme-linked immunoassay (ELISA) has been considered the ‘gold standard’ saliva analysis procedure (Fahlman & Engels, 2005; Gleeson et al., 1999). However, ELISA experimental procedures are comprehensive and time-consuming, and therefore may not be optimal for the applied sport science environment. Hopkins (2000) reported that athlete-monitoring tests should be easy to administer, require minimal technology and be able to obtain highly reliable results. Recently, a novel bio-sensory device has been developed with the capacity to perform salivary analysis remotely. The Individual Profiling (IPRO, IPRO Interactive, Wallingford, UK) point of care system is a portable immunoassay method that has been reported to reliably determine salivary concentrations of sIgA and sCort. Coad et al. (2015) demonstrated ‘high’ reliability (Hopkins, 2000) with concurrent sampling (ICC = 0.890, CV = 9.4%) as well as validity against the ELISA (r = 0.93, p < 0.01) for resting sIgA concentration in recreationally-active individuals. Fisher et al. (2015) reported similar results for resting sCort concentration, establishing duplicate and intra-day reliability (ICCs = 0.868; 0.904, respectively), as well as validity against the ELISA method (p = 0.881) in young healthy adults. These findings support claims that the IPRO can determine sCort and sIgA concentrations consistently across brief (i.e., < 30 min) retest intervals with a high level of validity.
Fisher et al. (2015) also evaluated the inter-day reliability of the IPRO to determine sCort at a 7-d retest interval. However, the ICC was 0.685, which is considered ‘questionable’ according to Hopkins (2000). In addition, no previous study has investigated the inter-day reliability of measuring sIgA using the IPRO point of care system. Given the longitudinal changes typically observed in sCort and sIgA over the course of a training intervention or competition, the establishment of inter-day reliability is essential. If they are to be used by sports scientists and coaches, any perturbations in sCort and sIgA concentration can then be considered meaningful of the external factor of particular interest (i.e., chronic exercise, increased training load etc.).

Sprint-cycling is considered a reliable mode of exercise as performance and physiological variables have been shown to be reproducible when tests are repeated under the same conditions (Bellinger & Minahan, 2014; Watt et al., 2002). Accordingly, it seems plausible to assume that the sCort and sIgA response to sprint-cycling may also be repeatable. For valid conclusions to be drawn regarding changes in sCort and sIgA in response to exercise, the reliability of the variables in question must first be established. Therefore, the aims of the present study were to: 1. Assess the inter-day reliability of the IPRO to determine resting sCort concentration and rate of sIgA secretion across a 1-wk interval, and 2. Evaluate the reproducibility of the sCort and sIgA response to sprint-cycling exercise by sampling saliva before and after completion of a repeated Wingate Anaerobic Test (WAnT).
5.3 Methods

5.3.1 Participants

Fourteen healthy men (31.9 ± 10.7 y, 180.9 ± 6.2 cm, 81.3 ± 9.3 kg) participated in the present study. Participants were considered recreationally-active, completing > 3-6 h·wk⁻¹ of moderate-intensity exercise. All participants reported to have very similar weekly routines regarding personal, part-time work and study commitments. All participants were informed of the study requirements and provided written informed consent. The study was conducted at the Griffith University Sports Science laboratory and was approved by the Griffith University Human Research Ethics Committee.

5.3.2 Experimental design

Participants attended the laboratory on three separate occasions separated by 7 d and standard laboratory conditions were maintained during testing (temperature: 23 ± 1°C; humidity: 60 ± 2%). The initial laboratory visit was used to familiarise the participants with the exercise protocol that comprised two, 30-s Wingate Anaerobic Tests separated by 3.5 min (2 x WAnT) performed on the Wattbike cycle ergometer (Wattbike Pro, Nottingham, UK). The remaining two visits were used for experimental testing, were performed at the same time of day and the instructions to participants, as well as the exercise and sampling protocols were identical.

Each participant was asked to abstain from strenuous exercise, caffeine and alcohol for 24 h. Participants were asked to consume a healthy diet and complete a 24-h diet
diary leading up to the first 2xWAnT trial (T1) that was then replicated in the 24 h preceding the second trial (T2). In addition, participants were asked not to consume any food or clean their teeth for 2 h before performing the 2xWAnT. Upon reporting to the laboratory, participants’ body mass was measured (SECA Birmingham, UK) and they were asked to complete a perceived stress scale and a 1-night sleep quality questionnaire to control for sleep and perceived stress between the two testing sessions. Where a participant reported they had experienced ‘poor’ sleep quality or greater than ‘low’ perceived stress, their experimental trial was performed the following day.

**5.3.3 Repeated Wingate Anaerobic Test protocol (2 x WAnT)**

Each 2xWAnT experimental trial was preceded by a standardized warm-up which consisted of 2 min of cycling at 2.5 W·kg⁻¹ followed 2 min at 3 W·kg⁻¹, and two, 4-s maximal sprints separated by 30 s of passive recovery. Following completion of the warm-up there was a 5-min rest period were participants were instructed to sit passively before a standardized countdown initiated the start of the first WAnT (WAnT₁). The 2xWAnT consisted of two, 30-s maximal sprints separated by 3-min active recovery (~ 50 W) and 30-s passive recovery (seated quietly on the Wattbike) in which time participants were instructed to re-position themselves for the start of second WAnT (WAnT₂). WAnT₂ was followed by 3-min active recovery at ~50 W. During each WAnT, participants were provided strong verbal encouragement and the time remaining after 15 s, every 5 s. The gearing, saddle and handlebar height and position (in or out of the saddle) on the Wattbike were self-selected by participants during the familiarisation session and then replicated during each WAnT.
The computer attached to the Wattbike recorded mean and peak power output, as well as mean cadence during each WAnT. Blood was sampled via an earlobe capillary and analysed for lactate concentration using a Lactate-Pro analyser (Arkay, Japan). Measurements were taken 5 min after completion of WAnT$_2$. Heart rate (HR) was measured continuously (RS800cx, Polar Electro Oy, Finland) during 2xWAnT trials with peak HR recorded immediately following each WAnT.

### 5.3.4 Saliva sampling

Resting and post-exercise saliva samples were collected 5 min before and 15 min after completion of the 2xWAnT. Participants rinsed their mouth with water 10 min prior to saliva collection. Unstimulated, whole saliva was collected using an IPRO oral fluid collector (OFC, IPRO Interactive, Wallingford, UK). Participants placed one OFC swab on top of their tongue and closed their mouth. When 0.5 mL of saliva had been absorbed by the OFC, an indicator line of the swab stem turned bright blue at which point the OFC was removed from the participant’s mouth and placed into a 3-mL buffer solution for analysis using an IPRO Lateral Flow Device (LFD) and LFD Reader (IPRO Interactive, Wallingford, UK). The time taken to collect saliva samples was recorded in minutes and seconds for the subsequent calculation of flow rate. sIgA concentration was then multiplied by the flow rate to express the results as a function of time (i.e., rate of sIgA secretion; $\mu$g·min$^{-1}$). The method of analyses to sCort (ng·mL$^{-1}$) and sIgA concentrations (µg·mL$^{-1}$) have been described in detail elsewhere (Coad et al., 2015; Fisher et al., 2015).
5.3.5 Perceived stress and sleep quality

Subjective stress and sleep quality were measured using the Perceived Stress Scale (PSS) and the Groningen Sleep Quality Scale (GSQS). The PSS is a 14-item self-report measure of feelings attributable to stress over the previous week. It is rated on a 5-point Likert scale (i.e., 0 = never; 4 = very often) with higher scores reflecting greater perceived stress. The GSQS is a 15-item, true or false self-report measure of factors attributable to sleep quality from the previous night (i.e., “I feel I slept poorly last night”). GSQS scores range from 0 to 14, a higher score indicating lower subjective quality of sleep.

5.3.6 Data analysis

Mean PSS and PSQS scores across the two experimental trials were compared using independent samples t-tests. Performance and physiological variables were compared using a within-subject design ANOVA with repeated measures. Performance and physiological data were log transformed and analysed using an excel spreadsheet for reliability as described by Hopkins (2000). Inter-day reliability for cycling performance and physiological variables was analysed using intra-class correlations. An individual’s coefficient of variation (CV %) for a specific outcome variable was calculated as the standard deviation of an individual’s repeated measurement, expressed as a percentage of their individual mean score. Typical error is presented as the CV % and as an absolute value along with the upper and lower 90% confidence interval (CI). Statistical significance was accepted at $p < 0.05$. 

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5.4 Results

There were no differences in PSS or GSQS scores between experimental trials (T1: 9 ± 2.6, T2: 9 ± 2.5; \( p = 0.391 \), T1: 1.5 ± 2.9, T2: 1.6 ± 2.8; \( p = 0.341 \), respectively). The performance and physiological variables for each trial are shown in Table 5.1. There was no difference in resting sCort between trials (\( F = 0.019, p = 0.892 \)), whereas sCort increased from resting after the 2xWAnT in both trials (T1: \( F = 33.111, p < 0.001 \); T2: \( F = 35.936, p < 0.001 \)). There was no difference in post-exercise sCort between trials (\( F = 0.886, p = 0.364 \)). No difference was observed in resting rate of sIgA secretion between trials (\( F = 0.219, p = 0.647 \)). The 2xWAnT elicited a decrease in rate of sIgA secretion in both trials (T1: \( F = 14.690, p = 0.002 \); T2: \( F = 14.100, p = 0.002 \)). However, post-exercise rate of sIgA secretion was significantly lower (\( F = 6.293, p = 0.026 \)) in T1 compared to T2.

There was no significant difference between trials for WAnT\(_1\) mean power (\( F = 1.982, p = 0.183 \)), mean cadence (\( F = 0.843, p = 0.375 \)) and peak HR (\( F = 0.923, p = 0.354 \)). WAnT\(_1\) peak power was significantly higher in T2 compared to T1 (\( F = 12.973, p = 0.003 \)). There was also no significant difference between trials for WAnT\(_2\) peak power (\( F = 2.747, p = 0.121 \)), mean power (\( F = 0.001, p = 0.975 \)), mean cadence (\( F = 0.399, p = 0.538 \)) and peak HR (\( F = 0.027, p = 0.872 \)). Peak power (\( F = 15.071, p = 0.002 \)), average power (\( F = 39.216, p < 0.001 \)) and mean cadence (\( F = 26.975, p < 0.001 \)) decreased from WAnT\(_1\) to WAnT\(_2\) in both trials. However, there was no change in peak HR from WAnT\(_1\) to WAnT\(_2\) (\( F = 0.084, p = 0.776 \)). No significant variance was revealed for BLa\(^{-}\) concentration between trials following completion of the 2xWAnT.
All reliability measures are shown in Table 5.2. The mean reliability of the physiological variables, expressed as the coefficient of variation (CV; %) and the typical error of measurement over the two trials were resting sCort 9.4%, 0.14 ng·mL$^{-1}$ (95% CL 0.1-0.2), post-exercise sCort 11.9%, 0.44 ng·mL$^{-1}$ (95% CL 0.3-0.7), resting rate of sIgA secretion 7.4%, 85.5 µg·min$^{-1}$ (95% CL 65.2-127.1), post-exercise rate of sIgA secretion 10.5%, 82.9 µg·min$^{-1}$ (95% CL 63.2-123.1), WAnT$^1$ peak HR 2.7%, 4.1 beats·min$^{-1}$ (95% CL 3.2-6.1), WAnT$^2$ peak HR 1.4%, 2.3 beats·min$^{-1}$ (95% CL 1.8-3.4), BLa$^-$ 6.2%, 0.7 mmol·L$^{-1}$ (95% CL 0.5-0.1). The cycling performance variables also displayed ‘acceptable’ reliability between trials with WAnT$^1$ peak power 3.5%, 39.7 W (95% CL 30.3-59.0), mean power 3.4%, 23.9 W (18.2-35.5), mean cadence 3.5%, 4.3 rev·min$^{-1}$ (95% CL 3.3-6.4) and WAnT$^2$ peak power 5.6%, 51.5 W (95% CL 39.3-76.6), mean power 3.0%, 17.8 W (95% CL 13.6-26.4), mean cadence 3.5%, 3.9 rpm (95% CL 3.0-5.8) displaying values that are considered within the commonly reported reliability criteria in athletic testing (CV < 10%). Differences from the mean for the two 2xWAnT trials for resting and post-exercise sCort and rate of sIgA secretion are shown in Figure 5.1.
Table 5.1. Mean (SD) performance and physiological variables determined during and after two 2xWAnT trials performed on a Wattbike.

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>sCort</strong> (ng·mL⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>1.75 ± 0.62</td>
<td>1.74 ± 0.59</td>
<td>1.75 ± 0.60</td>
</tr>
<tr>
<td>Post</td>
<td>4.73 ± 2.28</td>
<td>4.89 ± 2.24</td>
<td>4.81 ± 2.26</td>
</tr>
<tr>
<td><strong>Rate of sIgA secretion</strong> (µg·min⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>90.22 ± 59.87</td>
<td>89.14 ± 59.84</td>
<td>89.68 ± 55.41</td>
</tr>
<tr>
<td>Post</td>
<td>61.55 ± 43.77</td>
<td>66.48 ± 46.75</td>
<td>64.02 ± 45.26</td>
</tr>
<tr>
<td><strong>WAnT₁</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pk Power</td>
<td>1189.36 ± 289.87</td>
<td>1243.43 ± 300.06</td>
<td>1216.40 ± 294.97</td>
</tr>
<tr>
<td>Mean Power</td>
<td>715.93 ± 115.09</td>
<td>728.64 ± 109.68</td>
<td>722.29 ± 112.39</td>
</tr>
<tr>
<td>Mean Cadence</td>
<td>116.71 ± 8.24</td>
<td>118.21 ± 8.72</td>
<td>117.46 ± 8.48</td>
</tr>
<tr>
<td>HR</td>
<td>163 ± 12.61</td>
<td>164.5 ± 10.35</td>
<td>163.75 ± 11.48</td>
</tr>
<tr>
<td><strong>WAnT₂</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pk Power</td>
<td>1006.07 ± 183.85</td>
<td>1038.36 ± 188.25</td>
<td>1022.22 ± 186.05</td>
</tr>
<tr>
<td>Mean Power</td>
<td>581.36 ± 87.68</td>
<td>581.14 ± 87.05</td>
<td>581.25 ± 87.37</td>
</tr>
<tr>
<td>Mean Cadence</td>
<td>108.29 ± 6.55</td>
<td>109.21 ± 8.58</td>
<td>108.75 ± 7.57</td>
</tr>
<tr>
<td>HR</td>
<td>163.36 ± 7.68</td>
<td>163.21 ± 7.16</td>
<td>163.29 ± 7.42</td>
</tr>
<tr>
<td><strong>Bla</strong></td>
<td>13.06 ± 2.18</td>
<td>13.42 ± 1.41</td>
<td>13.24 ± 1.80</td>
</tr>
</tbody>
</table>

Table 5.2. Mean within subject intraclass correlation (ICC), typical error expressed as a coefficient of variation (CV %) and an absolute value (TEM) of the between-tests change.

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>CV</th>
<th>TEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>sCort</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>.96 (.89-.98)</td>
<td>9.4 (7.1-14.3)</td>
<td>.14 (.10-.20)</td>
</tr>
<tr>
<td>Post</td>
<td>.97 (.92-.99)</td>
<td>11.9 (8.9-18.1)</td>
<td>.44 (.34-.66)</td>
</tr>
<tr>
<td>Rate of sIgA secretion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>.99 (.98-1.00)</td>
<td>7.4 (5.6-11.2)</td>
<td>85.5 (65.2-127.1)</td>
</tr>
<tr>
<td>Post</td>
<td>.99 (.96-.99)</td>
<td>10.5 (7.9-16.1)</td>
<td>82.9 (63.2-123.1)</td>
</tr>
<tr>
<td>WAnT1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pk Power</td>
<td>.98 (.96-.99)</td>
<td>3.5 (2.6-5.2)</td>
<td>39.7 (30.3-59.0)</td>
</tr>
<tr>
<td>Mean Power</td>
<td>.96 (.91-.99)</td>
<td>3.4 (2.6-5.1)</td>
<td>23.9 (18.2-35.5)</td>
</tr>
<tr>
<td>Mean Cadence</td>
<td>.78 (.51-.91)</td>
<td>3.5 (2.7-5.3)</td>
<td>4.3 (3.3-6.4)</td>
</tr>
<tr>
<td>Peak HR</td>
<td>.89 (.74-.96)</td>
<td>2.7 (2.0-4.0)</td>
<td>4.1 (3.2-6.1)</td>
</tr>
<tr>
<td>WAnT2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pk Power</td>
<td>.94 (.85-.98)</td>
<td>5.6 (4.2-8.4)</td>
<td>51.5 (39.3-76.6)</td>
</tr>
<tr>
<td>Mean Power</td>
<td>.97 (.92-.99)</td>
<td>3.0 (2.3-4.5)</td>
<td>17.8 (13.6-26.4)</td>
</tr>
<tr>
<td>Mean Cadence</td>
<td>.82 (.59-.92)</td>
<td>3.5 (2.6-5.2)</td>
<td>3.9 (3.0-5.8)</td>
</tr>
<tr>
<td>Peak HR</td>
<td>.92 (.80-.97)</td>
<td>1.4 (1.1-2.1)</td>
<td>2.3 (1.8-3.4)</td>
</tr>
<tr>
<td>BLa`</td>
<td>.88 (.71-.95)</td>
<td>6.2 (4.7-9.3)</td>
<td>0.7 (0.5-1.0)</td>
</tr>
</tbody>
</table>

Note. sCort – Salivary cortisol concentration. sIgA – Salivary Immunoglobulin-A. WAnT1 – Wingate Anaerobic Test Trial 1. WAnT2 – Wingate Anaerobic Test Trial 2. HR – Heart rate. Bla` – Blood lactate.
Figure 5.1. Difference (%) of each individual trial from the mean of two trials for each participant for (A) Resting Sal-C, (B) Post-exercise Sal-C, (C) Resting s-IgA and (D) Post-exercise s-IgA.

5.5 Discussion

In the present study, we demonstrated the IPRO to be a reliable measure of determining sCort concentration and rate of sIgA secretion at rest and after sprint-cycling exercise. Resting sCort concentration and rate of sIgA secretion, and post-exercise sCort concentration were not different when comparing the two trials in the recreationally-active men. Post-exercise rate of sIgA secretion was lower in T1 compared to T2. Nevertheless, the intra-class correlation coefficients ranged from
0.96 – 0.99 indicating “excellent” reliability (Hopkins, 2000). We also demonstrated the IPRO to be sensitive to supramaximal exercise responses in sCort and rate of s-IgA secretion. SCort increased while rate of sIgA secretion decreased, in both trials, following completion of the 2xWAnT.

The present study suggests what could be considered a worthwhile change (Hopkins, 2004) in either sCort concentration or rate of sIgA secretion in response to a certain effect (i.e., exercise) in healthy active males. For example, the typical error for resting rate of sIgA secretion in the present study was 7.4%. Therefore, coaches and athletes would be ‘reasonably confident of a worthwhile change’ (Hopkins, 2004) where an increase in resting rate of sIgA secretion of 3.7% (i.e., half the typical error) or 3.31 µg·mL⁻¹ is observed. According to Hopkins (2014), athletes should aim to improve by double the typical error (i.e., 14.8% for resting rate of sIgA secretion), or 13.27 µg·mL⁻¹, from an initial resting rate of sIgA secretion of 89.68 µg·mL⁻¹. However, in the case of sIgA secretion, the rate or percent improvement needed to impact mucosal immune function is unknown. Furthermore, the typical error value was derived from a relatively small number of healthy active males. Therefore, further research may determine what could be considered a ‘biological’ improvement in mucosal immune function.

The reliability of the IPRO method for measuring resting sCort concentration has previously been assessed by Fisher et al. (2015). The authors investigated the duplicate, intra- (concurrent sampling) and inter-day reliability (time interval not given) in recreationally-active university students, revealing ICCs of 0.868, 0.904 and 0.658, respectively. Although Fisher et al. (2015) established “excellent” duplicate
and intra-day reliability, inter-day reliability is considered “questionable” (Hopkins, 2000). The present study demonstrates stronger reliability (ICC = 0.96) than that of Fisher et al. (2015) at a 7-d retest interval. The authors indicated they did not measure and control for perceived psychological and physical stress; factors that contribute to cortisol secretion at rest (van Eck et al., 1996). Furthermore, it is unknown whether the study by Fisher et al. (2015) measured and controlled for subjective sleep quality between testing sessions. The present study monitored perceived stress and subjective sleep quality, showing no change in PSS and GSQS scores between trials. Therefore, differences in stress and sleep quality may explain the “questionable” inter-day reliability in the study by Fisher et al. (2015).

To our knowledge, this is the first study to assess the inter-day reliability of rate of resting sIgA secretion. Coad et al. (2015) investigated the intra-day (concurrent sampling) reliability of the IPRO method for measuring resting sIgA concentration in physically-active university students. The authors demonstrated an ICC of 0.89 indicating “very good” reliability at an instantaneous retest interval. The evaluation of intra-day reliability is essential so that any immediate changes in rate of sIgA secretion can then be considered meaningful in response to the external factor (i.e., acute exercise). Nevertheless, the ability to establish inter-day reliability of the IPRO method for measuring rate of sIgA secretion will enable coaches and sport scientists to: 1. Monitor immunological status in athletes at longer retest intervals during periods of increased training load or competition, 2. Understand immunological trends in different sporting environments, and 3. Make practical decisions regarding training modalities and recovery to minimise susceptibility to illness.
The present study demonstrated an increase in sCort following completion of the 2xWAnT. Similar findings have been highlighted in research investigating the effects of supramaximal cycling exercise on adrenocortical function that employed the “gold standard” ELISA method (Crewther et al., 2010; Thomas et al., 2009). Thomas et al. (2009) observed an increase in sCort measured 5 min after completion of a repeated-sprint cycle ergometry test in high school students (pre: 1.3 ± 6.9 ng·mL⁻¹, post: 2.0 ± 1.2 ng·mL⁻¹; p < 0.05). The resting sCort concentration of the high school students in the study by Thomas et al. (2009) is similar to that of the recreationally-active men in the present study (mean: 1.75 ± 0.60 ng·mL⁻¹). However, post-exercise sCort concentration was greater in the present study (4.81 ± 2.26 ng·mL⁻¹) as compared to that of Thomas et al. (2009) (2.0 ± 1.2 ng·mL⁻¹). Crewther et al. (2010) reported a sCort concentration increase, comparable to that of Thomas et al. (2009), following completion of a 30-s WAnT in healthy males. A 63 ± 29% increase in sCort concentration was demonstrated when measured 10-min post exercise compared to at rest. The larger post exercise sCort concentration observed in the present study may have been because the exercise stimulus was more severe than that elicited in the aforementioned studies. In contrast to the single 30-s WAnT employed by Crewther et al. (2010), the current study implemented two. However, it is difficult to quantify the differences in physical demand between the 2xWAnT and the repeated-sprint protocol used by Thomas et al. (2009). Nevertheless, the results are in agreement with previous research (Hayes et al., 2015) that high-intensity exercise causes an increase in cortisol secretion. Therefore, the IPRO method is sensitive to detect changes in sCort provoked by high-intensity exercise.
The post-exercise decrease in sIgA in the present study is in agreement with several previous studies that used the ELISA method for evaluating the mucosal immune function-response to exercise (Gleeson et al., 2000; Libicz et al., 2006; Nieman et al., 2002). Moreover, a study by Fahlman et al. (2001) found comparable results in active women following completion of an exercise protocol comparable to that in the present study. The authors implemented a 3xWAnT protocol and revealed a significant decrease in sIgA when comparing pre to post measures (pre: 55.8 ± 4.7 µg·min\(^{-1}\); 35.4 ± 3.6 µg·min\(^{-1}\); \(p < 0.05\)). Although the protocol in the present study only contained 2xWAnT, the results showed a ~38% decrease in sIgA as compared to a ~36% decrease in the study by Fahlman et al. (2001) after a short bout of high-intensity exercise. While it is difficult to compare absolute sIgA measures in the present study to those of Fahlman et al. (2001) due to the participant characteristics (i.e., gender, training status) and exercise protocol (i.e., number of WAnTs), the findings of the present study demonstrate the sensitivity of the IPRO method to detect a decrease in sIgA elicited by high-intensity exercise.

In order to determine a “meaningful” physiological response to exercise, the exercise protocol employed must show high repeatability when performed under the same conditions. Performance variables WAnT\(_1\) mean power and mean cadence, and WAnT\(_2\) mean power, peak power, and mean cadence were not different between the two trials. Peak power achieved in WAnT\(_1\) was significantly higher in T2 compared to T1 which may be attributed to a “learning effect” (Hopkins, 2000). Nevertheless, this did not affect the total work performed between trials (i.e., mean power) nor the cardiovascular and metabolic responses (i.e., peak HR, blood lactate, respectively). All performance and physiological variables showed ICC’s ranging 0.78 – 0.98
demonstrating “good” to “excellent” reliability (Hopkins, 2000) with CVs < 10%. These findings are in agreement with Watt et al. (2002) who previously determined the reliability of the 2xWAnT in physically-active men on a Lode Excaliber cycle ergometer. The mean CVs for WAnT₁ peak power (2.5%), mean power (1.7%) and WAnT₂ peak power (1.9%), mean power (1.8%) in the study by Watt et al. (2002) were smaller than those reported in the present study (WAnT₁: 3.5, 3.4%; WAnT₂: 5.6, 3.0%, respectively). Reasons for lower CVs in the study by Watt et al. (2002) may be related, in part, to the participants performing four trials of the 2xWAnT whereby the first trial was considered a ‘practice trial’ and reliability was calculated from the last three trials. Nevertheless, the present study demonstrated high reliability for the 2xWAnT to ensure post-exercise changes in sCort and rate of sIgA secretion were meaningful of the exercise protocol.

The present study demonstrated the IPRO a reliable method for determining resting and post-exercise sCort concentration and rate of sIgA secretion at a 7-d retest interval. Furthermore, we also established the IPRO method is sensitive in detecting a change in sCort concentration and rate of sIgA secretion in response to sprint-cycling exercise. These findings will allow Sport Scientists and coaches to utilise this method to monitor physiological stress and mucosal immunity in their athletes, and detect small but meaningful changes in these variables in response to external factors such as training load and competition.
Chapter 6: Mindfulness training attenuates the increase in salivary cortisol concentration associated with competition in highly-trained wheelchair basketball players

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6.1 Abstract

This study determined the effect of 8 wk of mindfulness training (MT) on salivary cortisol (sCort) and rate of salivary Immunoglobulin-A (sIgA) secretion in wheelchair-basketball players (Mindful group, m = 5, f = 3; Control group, m = 6, f = 2) during a competition period. The Mindful group completed 8 wk of MT in addition to training and competition. sCort and rate of sIgA secretion were measured at baseline (MT-BL), at 2-wk intervals (MT-2wk, MT-4wk, MT-6wk, respectively), the end (MT-8wk) of the intervention period and 2-wk following (Post-2wk). A significant time and group interaction was observed for sCort ($F = 3.297, p = 0.040$, $ES = 0.191$); sCort increased in the Control group from MT-BL to MT-2wk ($p = 0.001$) and remained significantly elevated at MT-4wk ($p = 0.013$) and MT-6wk ($p = 0.002$). sCort decreased from MT-6wk to MT-8wk ($p < 0.001$) and concentrations were not different at MT-8wk and Post-2wk to MT-BL ($p > 0.05$). Mindful group sCort increased from MT-BL to MT-2wk ($P = 0.042$) but decreased to concentrations no different to MT-BL for the rest of the intervention period ($p > 0.05$). There were no group differences in rate of sIgA secretion during the intervention ($p = 0.810$). It was concluded that 8 wk of MT attenuated the increase in sCort associated with the competition period. MT may be a useful recovery tool to manage the onset of physiological stress in athletes during competition.
6.2 Introduction

During a competitive season in team-sport, elite athletes are required to frequently travel, perform at their best and continue to train at a high intensity. Consequently, athletes are exposed to increasing amounts of physical and psychological stress (Fernandez-Fernandez et al., 2015). If this additional stress is not monitored and managed effectively, performance may deteriorate and/or athletes may have an increased susceptibility to injury and/or illness (Williams & Andersen, 1998).

Increases in physical and/or psychological stress can result in the chronic elevation of the hormone cortisol at rest. Indeed, prolonged elevations in basal cortisol concentration generally reflect long-term training as well as competition stress, and have been linked to overtraining syndrome prevalence in athletes (Eichner, 1995; Kellmann, 2010). Furthermore, prolonged periods of intensified intermittent strenuous exercise, competition and training also pose a challenge to mucosal immune function as observed by decreased resting levels of secretory Immunoglobulin-A in the saliva (sIgA) in elite athletes (Libicz, Mercier, Bigou, Le Gallais, & Castex, 2006). Reductions in sIgA have been identified as a risk factor of subsequent upper respiratory tract infection incidence in elite athletes (Gleeson et al., 2012). Therefore, the measurements of cortisol and sIgA are useful monitoring tools for the management of training and competition loads as well appropriate recovery strategies during a competition period to maintain physical and mental wellbeing and optimize sports performance.
Mindfulness training (MT) is a form of meditation and practice of “non-judgmental observation of the ongoing stream of internal and external stimuli as they arise” (Baer, 2003, p. 125). It is thought that MT provides the individual with a self-regulatory process; an ability to objectively reappraise stressors and thereby interrupt their own psychological re-activity and concomitant increase in the psychophysiological stress response (Rosenzweig, Reibel, Greeson, & Edman, 2007). There is evidence that MT can reduce stress in cancer sufferers, with results indicating reductions in high plasma- (Witek-Janusek, et al., 2008) and salivary- (Carlson, Speca, Patel, & Goodey, 2004; Matousek, Pruessner, & Dobkin, 2011) cortisol levels following completion of MT interventions. In addition, MT has been shown to improve mucosal immune function, with an increase in sIgA in healthy university students (Fan, Tang, Ma, & Posner, 2010). Furthermore, the application of MT to sports performance indicates improved coach’s performance ratings (Gardner, & Moore, 2007), increases in ratings of experiential acceptance, dispositional flow, and mindfulness attention (Schwanhausser, 2009), increases in national ranking (Bernier, Thienot, Cordon, & Fournier, 2009), and longitudinal improvements in running time (Thompson, Kaufman, De Petrillo, Glass, & Arnkoff, 2011). Despite these favourable findings, few studies have examined the effect of MT on stress-related changes in cortisol and mucosal immune function in athletes.

A study by John, Verma, and Khanna (2011) reported significant reductions in pre-competition sCort and increased shooting performance in elite shooters following 4 wk of MT. This finding indicates that MT is associated with an attenuation of the acute anticipatory increase in physiological stress, as determined by sCort, prior to a competition. However, it remains to be determined whether MT can alter basal
concentrations of sCort in team-sport athletes that may be chronically-elevated during a period of competition or increased training load. This is important as MT may help to manage the onset of psychological and physiological stress that is attributed to competition. We hypothesised that MT will attenuate the chronic increase in physiological stress associated with training and competition. Furthermore, it remains to be determined whether MT can alter mucosal immune function in a sporting population. If MT can improve mucosal immune function, this may be beneficial in reducing the risk of illness in athletes during periods of competition. Therefore, the purpose of the present study was to investigate the effect of a mindfulness training intervention on indices stress (sCort) and mucosal immune function (sIgA) in a team of highly-trained wheelchair basketball players.

6.3 Methods

6.3.1 Participants

Sixteen wheelchair-basketball players participated in this randomised controlled study. All participants had been members of the state wheel-chair basketball squad for \( \leq 2 \) yr and were considered highly-trained, completing \( >15 \text{ h \cdot wk}^{-1} \) of training while playing at the same level of competition during the experiment. Participants were randomly assigned to two groups: The Mindful group \((n = 8; 5 \text{ males}, 3 \text{ females}; \text{ age: } 27.0 \pm 5.8 \text{ yr})\) and the Control group \((n = 8; 6 \text{ males}, 2 \text{ females}; \text{ age: } 24.8 \pm 5.1 \text{ yr})\), and had no prior experience in any style of meditation. All participants were informed of the study requirements and provided written informed consent. The study was conducted at the state training facility and was approved by the Griffith University
Human Research Ethics Committee. It must be noted that no attrition occurred in the present study.

6.3.2 Experimental design

Participants were required to attend a familiarisation session and participate in an 8-wk intervention as well as follow-up session to complete the present study. The 8-wk intervention was implemented to coincide with a 7-wk period of competition (i.e., Competition period); baseline and end-intervention testing occurred 3 d prior to the commencement, and 3 d following (respectively) the completion of the Competition period. During the familiarisation session, participants were familiarised with all study procedures and the Mindful group was given a presentation explaining the origins of mindfulness and what they were to experience during meditations and teachings. In addition, the Control group were notified that they would be educated on and have access to the MT intervention and the Smiling Mind smart phone application once the experiment had concluded. To minimize crossover effects, the Mindful group were asked to refrain from discussing the MT intervention with the Control group until the experiment concluded.

During the Competition period, participants were required to play between three and six games each week as well as continue with regular training. Games occurred anywhere from Wednesday to Sunday each week during the competition period. During the intervention period, the Control group completed training and competition as per usual while the Mindful group completed an 8-wk mindfulness training intervention in addition to training and competition. The duration of the intervention
(i.e., 8 wk) was chosen to match previous clinical MT interventions (Baer, 2003). The intervention was a graded approach to MT; the first 2 wk consisted of the Mindful group completing an 8-min meditation session, followed by 10-min of mindfulness exercises, 5 times each week. The following 6 wk consisted of the Mindful group completed a 45-min meditation session, followed by 5 min of exercises, 5 times each week. The mindfulness meditations and teachings were provided to the Mindful group in a smart-phone application. All participants attended testing sessions that occurred midweek (i.e., Wednesdays) at baseline (0 wk; MT-BL), at 2-wk intervals (beginning of wk 3, wk 5, wk 7; MT-2wk, MT-4wk, MT-6wk, respectively), the end (MT-8wk) of the intervention period and 2-wk following (Post-2wk). During all testing sessions, saliva samples were taken for the analysis of sCort and sIgA.

6.3.4 Mindfulness training and smart phone application

The mindfulness meditations and teachings used in the MT intervention were provided in a smart phone application, Smiling Mind (Smiling Mind, South Yarra, VIC, Australia), that was downloaded from Apple’s App Store (Apple Inc., Cupertino, CA, USA). Smiling Mind contains mindfulness programs that include meditations and exercises that outline the key aspects of traditional mindfulness practices. Meditations, exercises and the order of completion were pre-determined by the Chief Investigator. During the first 2 wk, the Mindful group completed five adult programs from the Smiling Mind application twice (i.e., one program each day, five programs each week), in consecutive order. Each adult program contained a guided 8-min meditation and approximately 10 min of brief, instructed exercises of varying length (i.e., 1 – 7 min). During the following 6 wk, Mindful group participants completed a
guided 45-min meditation and approximately 5 min of brief exercises selected from the *Bite Size* program, five times each week. During the meditations, participants were seated comfortably, in an upright posture, with their eyes closed. They were instructed to use the sensation of their breath as a focal point, while noticing other sensations in their body, sounds and feelings they may have been experiencing in a non-judgmental manner (Kabat-Zinn, 1994, 2011). Participants were given constant instruction during the 8-min meditations to aid them in maintaining present-moment awareness while the 45-min meditation was more independent as it contained longer periods of silence and less guidance. This allowed for the participants to utilize their skills gained from the introductory period training to maintain mindfulness during the meditation. Exercises included traditional mindfulness practices such as the *Body Scan*, which has previously been implemented in neuropsychological research (Ditto, Eclache, & Goldman, 2006; Hölzel, Carmody, et al., 2011) and incorporated into well-established clinical interventions (Carmody & Baer, 2008; Herbert & Forman, 2011; Kabat-Zinn, 1994). In the *Body Scan*, participants were either seated or lying down, and were instructed to focus their attention sequentially to different parts of their body while noticing sensations that may be present (Kabat-Zinn, 1994). The exercises completed from the adult program were similar to those completed in the *Bite Size* program but the adult program was longer in duration. The meditation duration during the final 6 wk of the intervention (i.e., 45 min) was chosen to match previous clinical research that has implemented MT interventions (Baer, 2003).

Before commencing a mindfulness meditation or exercise, participants set their smart phone to flight mode to avoid interruptions. All meditations and exercises were completed with headphones, to avoid audible distractions, and in the participant’s
own time at home. Participants completed a mindfulness-training diary to log meditations and exercises completed and to keep them motivated to complete the training period. In addition, the smart phone application logged and recorded all completed meditations and exercises. To ensure compliance, each participant’s training diary and smart application was reviewed during each testing session.

### 6.3.5 Saliva sampling

Cortisol and IgA concentrations were determined from salivary samples. Saliva collection occurred in the morning, at the same time of day, on the same day of the week, to avoid circadian effects. The competition and training schedule allowed for participants to avoid strenuous exercise 24 h prior to saliva collection. Unstimulated, whole saliva was collected using an IPRO oral fluid collector (OFC; IPRO Interactive, Wallingford, UK) and was analysed using an IPRO Lateral Flow Device (LFD) and LFD Reader (IPRO Interactive, Wallingford, UK). The method of collection and analyses to determine sCort (ng·mL\(^{-1}\)) sIgA concentration have been described in detail elsewhere (Coad, Mclellan, Whitehouse, & Gray, 2015; Fisher, McLellan, & Sinclair, 2015). In addition, the time taken to collect saliva samples was recorded in minutes and seconds for the subsequent calculation of flow rate. sIgA concentration was then multiplied by the flow rate to express the results as a function of time (i.e., rate of sIgA secretion; µg·min\(^{-1}\)). The inter-day reliability of the IPRO to determine resting sCort and rate of sIgA secretion has previously been established by MacDonald, Bellinger, and Minahan (2017) at a 7-d retest interval with coefficients of variation of 9.4% and 7.4%, respectively.
6.3.6 Statistical analyses

All data are presented as mean ± SD. Differences between groups (Mindful group vs Control group; independent variable) and changes in sCort concentration and rate of sIgA secretion (dependent variable) across the sampling sessions were assessed using fully factorial ANOVA with repeated measures. Where a significant interaction or main effect was observed between group or time, least squares difference pairwise comparisons were used. Partial Eta squared for effect size (ES) was used and the results were based on the following criteria: small (0.01 – 0.089), medium (0.09 – 0.249) and large (≤ 0.25). IBM SPSS Statistics for Windows (Version 22.0, IBM Corp., Armonk, NY) was used for all statistical analyses. Statistical significance was accepted at $P < 0.05$.

6.4 Results

sCort concentration and rate of sIgA secretion determined at each time point is presented in Figure 1 and Figure 2, respectively. A significant interaction between group and time was observed for sCort ($F = 3.297, p = 0.040, ES = 0.191$); there was a significant increase in sCort in the Control group from MT-BL (6.85 ± 7.34 ng·mL$^{-1}$) to MT-2wk (20.03 ± 12.57 ng·mL$^{-1}$; $p = 0.001, 95\%$ CI -19.72 – -6.62) and sCort remained significantly elevated, compared to MT-BL, at MT-4wk (18.28 ± 11.83 ng·mL$^{-1}$; $p = 0.013, 95\%$ CI -20.05 - -2.80) and MT-6wk (19.64 ± 10.59 ng·mL$^{-1}$; $p = 0.002, 95\%$ CI -19.79 - -5.76). sCort significantly decreased from MT-6wk to MT-8wk (5.80 ± 3.38 ng·mL$^{-1}$; $p < 0.001, 95\%$ CI 8.61 – 19.06) and concentrations were not different at MT-8wk and Post-2wk (5.51 ± 3.05 ng·mL$^{-1}$) to MT-BL ($p = 0.609,$
95% CI -3.29 – 5.40; \( p = 0.479 \), 95% CI -2.63 – 5.34; respectively). However, sCort increased in the Mindful group from MT-BL to MT-2wk (5.95 ± 3.51 ng·mL\(^{-1}\), 12.76 ± 8.38 ng·mL\(^{-1}\); \( p = 0.042 \), 95% CI -13.38 - -0.28) but decreased to concentrations no different to MT-BL at MT-4wk (9.46 ± 8.28 ng·mL\(^{-1}\); \( p = 0.396 \), 95% CI -12.15 - -5.10), MT-6wk (7.06 ± 1.94 ng·mL\(^{-1}\); \( p = 0.737 \), 95% CI -8.13 – 5.90), MT-8wk (6.46 ± 1.70 ng·mL\(^{-1}\); \( p = 0.802 \), 95% CI -4.86 – 3.83) and Post-2wk (2.83 ± 1.01 ng·mL\(^{-1}\); \( p = 0.117 \), 95% CI -0.88 – 7.09). In addition, a difference in sCort was observed between the Mindful group and Control group at MT-6wk (\( p = 0.005 \), \( ES = 0.438 \)).

Figure 6.1. Mean group sCort concentrations measured at baseline, during, after and 2-wk following the intervention. Shaded plot area represents the 7-wk Competition period. *Significantly different from individual group MT-BL (\( P < 0.05 \)). \# Significant difference between group sCort concentrations (\( P < 0.05 \)). Data presented as mean ± standard deviation.
There was no significant interaction between the independent variables of group and time for rate of sIgA secretion ($F = 1.035, p = 0.372$). However, there was a main effect of time ($F = 9.356, p = 0.001, ES: 0.401$); rate of sIgA secretion significantly increased from MT-BL (Mindful: $68.52 \pm 46.71 \, \mu g\cdot min^{-1}$, Control: $49.34 \pm 51.89 \, \mu g\cdot min^{-1}$) to MT-2wk (Mindful: $72.35 \pm 41.63 \, \mu g\cdot min^{-1}$, Control: $153.18 \pm 119.84 \, \mu g\cdot min^{-1}$; $p = 0.021, 95\% \, CI \, -98.33 \, -9.34$), in both groups and, compared to MT-BL, rate of sIgA secretion remained elevated at MT-4wk (Mindful: $144.29 \pm 90.58 \, \mu g\cdot min^{-1}$, Control: $153.96 \pm 204.12 \, \mu g\cdot min^{-1}$; $p = 0.010, 95\% \, CI \, -155.01 \, -25.38$) and MT-6wk (Mindful: $216.22 \pm 168.96 \, \mu g\cdot min^{-1}$, Control: $205.26 \pm 188.38 \, \mu g\cdot min^{-1}$; $p = 0.001, 95\% \, CI \, -229.02 \, -74.60$). Rate of sIgA secretion reduced from MT-6wk to MT-8wk (Mindful: $98.38 \pm 54.62 \, \mu g\cdot min^{-1}$, Control: $73.12 \pm 95.31 \, \mu g\cdot min^{-1}$; $p = 0.003, 95\% \, CI \, 50.87 \, -199.11$) and MT-8wk and Post-2wk (Mindful: $39.21 \pm 31.73 \, \mu g\cdot min^{-1}$, Control: $69.34 \pm 90.77 \, \mu g\cdot min^{-1}$) rate of sIgA secretion were not different to MT-BL ($p = 0.064, 95\% \, CI \, -55.48 \, -1.84$; $p = 0.704, 95\% \, CI \, -21.12 \, -30.44$, respectively). There was no main effect of group ($F = 0.060, p = 0.810$) indicating that there were no group differences in rate of sIgA secretion across any of the time points.
Figure 6.2. Mean group rate of sIgA secretion measured at baseline, during, after and 2-wk following the intervention. Shaded plot area represents the 7-wk Competition period. *Main effect of time when compared to MT-BL ($P < 0.05$). Data presented as mean ± standard deviation.

6.5 Discussion

The purpose of the present study was to determine if 8 wk of MT altered basal sCort concentration and the rate of sIgA secretion in wheelchair-basketball players measured during a competition period. We found that sCort concentrations increased and remained elevated in the Control group in response to the competition period, and recovered following the conclusion of the competition period. Conversely, although sCort increased in the Mindful group from MT-BL to MT-2wk, it returned to a concentration no different to MT-BL at MT-4wk and remained for the rest of the intervention period. In contrast, MT did not alter resting rate of sIgA secretion as
there was no difference between groups at any of the time points across the competition period.

John et al. (2011) examined the impact of 4 wk of MT on anticipatory stress experienced immediately before competition in rifle shooters. sCort was measured prior to competitions that occurred before and after the completion of 4 wk of MT. John et al. (2011) observed significantly lower cortisol concentrations (before: 1.33 ± 0.06 ng·mL\(^{-1}\), after: 0.66 ± 0.07 ng·mL\(^{-1}\); \(p < 0.001\)) in the rifle shooters following MT and concluded that MT can be used to alleviate anticipatory increases in stress related to competition. The results of present study and that of John et al. (2011) suggest that mindfulness training is an effective tool for managing the competitive-stress related increase in sCort in athletes.

Unlike the findings of John et al. (2011), the present study did not observe a reduction in sCort. However, it is difficult to compare the present study to the study by John et al. (2011) due to differences in times of sCort analysis. The present study measured basal sCort without the ‘immediate stress’ that may be caused by competition. Therefore, it is possible that sCort was at a ‘true’ resting concentration when measured at MT-BL in the present study. Whereas, John et al. (2011) measured sCort immediately prior to competition, thus, it is possible that sCort was already elevated allowing potential for a reduction following MT. This notion is supported by the findings of Carlson et al. (2004) who investigated the effect of the 8-wk Mindfulness Based Stress Reduction (MBSR) program on diurnal patterns of sCort in breast and prostate cancer sufferers. Although there results revealed no overall changes in mean daily sCort concentrations, they found that participants with initially elevated sCort
concentrations did have significant reductions ($P$ value not given) in sCort following completion of MBSR. Therefore, if MT-BL sCort were considered to already be at a ‘normal’ concentration (i.e., not affected by a stressor) in the Mindful group in the present study, there would have been limited potential for a positive change (i.e., reduction) in response to MT.

It is well established that increases in training load and competition will cause an elevation in basal cortisol concentration (Kirwan et al., 1988; Urhausen, Kullmer, & Kindermann, 1987). Therefore, it is not surprising that basal sCort increased in the Control Group in response to the commencement of the Competition period. Nonetheless, although sCort increased in the Mindful group from BL to Wk3, it returned to a concentration no different to BL at Wk5 and for the remainder of the intervention period. Previous clinical studies have highlighted the neurological benefits of MT on brain regions associated with attention regulation (Grant, Courtemanche, Duerden, Duncan, & Rainville, 2010), body awareness (Hölzel et al., 2011; Hölzel et al., 2007; Lazar et al., 2005), and emotion regulation (Hölzel et al., 2007); regions of the brain associated with the cognitive mechanisms attention regulation, body awareness and emotion regulation, respectively. In addition, a review by Hölzel et al. (2011) reported these mechanisms work synergistically to develop increased self-regulation. Therefore, it can be postulated that the MT intervention caused neurological benefits in the Mindful group that resulted in an attenuation of their stress response during the Competition period. Nevertheless, as this has not yet been examined in a sporting population, further research would be necessary to determine any potential neurological, cognitive or attentional effects.
To our knowledge, only one previous study has investigated the effect of a mindfulness-based intervention on sIgA. Fan et al. (2010) investigated the effect of Integrated Body-Mind Training, a 4-wk MT intervention (experimental group), as compared to a 4-wk relaxation intervention (control group) on mucosal immune function in healthy university students. The authors demonstrated an increase in basal sIgA concentrations in the experimental group, whereas there was no change in the control group. Fan et al. (2010) concluded that MT produces positive changes in the mucosal immune system and that long-term practice of MT may result in improved health and stress management. However, the present study observed no differences in rate of sIgA secretion between the Mindful group and the Control group at any of the time points.

Both heavy-intensity exercise and repeated bouts of severe-intensity exercise cause a decrease in sIgA in athletes (Fahlman, Engels, Morgan, & Kolokouri, 2001; Libicz et al., 2006). Furthermore, it is well established that low sIgA concentration and rate of sIgA secretion is linked to subsequent upper respiratory tract infection (URTI) incidence in elite athletes (Fahlman & Engels, 2005; Gleeson, 2000). The present study investigated whether mindfulness training could have a positive effect on mucosal immunity by increasing rate of IgA secretion in the wheelchair basketball players and therefore, attenuate the risk of URTI. However, rate of sIgA secretion increased, in both the Mindful and Control groups, from MT-BL to MT-2wk and rate of IgA secretion remained elevated through to MT-6wk and decreased at MT-8wk following the completion of the Competition period. Therefore, it is possible that the Competition period was not intense enough to elicit a decrease in rate of sIgA secretion. Actually, the Competition period is the likely cause of the increase in rate
of sIgA secretion. This is supported by Gleeson (2000) who observed an increase in salivary sIgA concentrations during a final, 12-wk training cycle prior to the national swimming championships. Nevertheless, any increases in rate of sIgA secretion that may have been caused by the mindfulness training did not exceed the increases elicited by the Competition period.

It is noteworthy to mention the limitations of this study. Indeed, the relatively small sample size (n = 16) in this study may be seen as a limitation, and future research could replicate this experiment with a larger randomized controlled study. Nonetheless, the sample size in the present study is an accurate representation of the number of athletes typically seen in a sporting team or squad. There are also various factors that have been shown to affect sCort and rate of sIgA secretion such as minor inflammation, unforeseen life events, and/or personality that were not assessed during this experiment.

The present study demonstrated that 8 wk of MT attenuated the increase in basal sCort in a group of highly-trained wheelchair-basketball players during a competition period. We observed no effect of 8 wk of MT on rate sIgA secretion in the wheelchair-basketball players. It is well established that glucocorticoids (i.e., cortisol) exert an inhibitory effect on cells of the immune system (Dunn, 2007). Furthermore, previous researchers have highlighted an inverse relationship between sIgA and cortisol activity patterns during the first 30-min after awakening (Hucklebridge, Clow, & Evans, 1998). However, there was no relationship between sCort activity and rate of sIgA secretion in the present study. Future research investigations could
investigate the relationship between mucosal immune function and hypothalamic-pituitary-axis activity in athletes and how this may contribute to athletic performance.
CHAPTER 7: Statement of conclusions
7.1 General discussion

The efficacy of MT to improve health has been well established in both clinical and healthy populations (Baer, 2003; Alberto Chiesa & Serretti, 2009). Previous studies have also highlighted the positive effect of MT in cognitive domains including sustained (Chambers et al., 2008; Jha et al., 2007), selective (Chan & Woollacott, 2007; Hodgins & Adair, 2010; Jha et al., 2007) and executive attention (Chan & Woollacott, 2007; Jha, Krompinger, & Baime, 2007; Tang et al., 2007), working memory (Chambers et al., 2008; Zeidan et al., 2010), and executive functions such autobiographical memory, cognitive inhibition, and cognitive flexibility (Heeren et al., 2009). Current research in the area of sport and cognitive function includes the examination of ‘higher-order’ cognitive skills, such as sport-specific decision-making (Buszard et al., 2013). In contrast, fundamental cognitive skills such as psychomotor function, vigilance, memory and executive function have traditionally been analysed for the assessment of, and recovery from, concussion injury (Collie et al., 2001; Schatz et al., 2006). However, recent evidence suggests that fundamental cognitive ability may be a predictor of non-contact injury risk (Swanik et al., 2007). Consequently, it seemed plausible to explore an intervention with the potential to increase or maintain fundamental cognitive function to reduce non-contact injury prevalence in team sports. Therefore, one aim of this thesis was to investigate whether MT can improve performance on a battery of tests that assess fundamental aspects of cognition in team-sport athletes.

Before the efficacy of MT for improving fundamental cognitive performance could be evaluated, it was necessary to determine a quantitative test of cognitive performance that could provide a reliable measurement for detecting small changes in cognitive
performance. Prior to this thesis, the CogState battery had been widely used in clinical research (Hammers et al., 2011; Lim et al., 2013) and had shown to be a reliable and valid measure of assessing several cognitive domains (i.e., psychomotor function, working memory, delayed recall etc.). However, the reliability of the CogState tests the Groton Maze Learning Task, Detection Task, Identification Task and the One Card Learning Task that assess the domains of executive function, psychomotor function, vigilance, visual learning and memory had not previously been established.

Furthermore, the reliability of the CogState battery of cognitive tests had never been established in a sporting population. If it were to be used to assess fundamental aspects of cognition in highly-trained athletes, Sports Scientists and coaches need to be confident that any perturbations in performance are representative of an external factor (i.e., supplementation, exercise etc.) and not of experimental noise. Data from Chapter 2: *Indices of cognitive function measured in rugby union players using a computer-based test battery* showed that performance of the Detection Task, Identification Task and the One Card Learning Task was repeatable at 30-min and 24-h retest intervals. The performance variables for the Detection Task, Identification Task and the One Card Learning Task displayed values that are within the commonly reported reliability criteria in athletic testing (CV: < 10%; ICC > 0.7; Hopkins, 2000). The reliability of the Groton Maze Learning Task was ‘questionable’ (Hopkins, 2000) (total errors mean CV: 19.4%) and, therefore, any subsequent results were interpreted with caution.

With the results of Experiment 1 (Chapter 2) in mind, the second experimental study of this thesis (Chapter 3) implemented the CogState battery containing the Groton
Maze Learning Task, Detection Task, Identification Task and the One Card Learning Task to examine the effects of a brief (20 min) mindfulness meditation session on cognitive performance in the domains of executive function, psychomotor function, vigilance, visual learning and memory (respectively). The premise behind this study was to explore whether improvements in cognitive performance may result after a single session of mindfulness meditation. A previous study reported improvements in mean RT of a psychomotor vigilance test after completing a 40-min concentrative meditation in university students (Kaul et al., 2010). However, we chose a 20-min meditation session as it may be more suitable for coaches and players in occasions with time constraints such as before a game or during at heavy training schedule. We found that the 20-min meditation session did not improve any of the performance variables from the cognitive tests in the team of highly-trained rugby union players. We concluded that a larger dose (i.e., longer or more frequent meditation sessions) may be required to evoke improvements in cognitive performance of the rugby union players. In addition, a learning effect was observed from performance of the Groton Maze Learning Task and for this reason, in addition to showing ‘questionable’ reliability in Chapter 2, it was removed from the CogState test battery for further examinations.

Previous studies have highlighted the chronic effects of MT interventions on cognitive performance in several domains, but not in a sporting population. This led us to hypothesise that 4 wk of MT (completing 20-min meditations three times each week) may elicit a chronic effect, as well as an acute effect following a meditation session on performance of the cognitive test battery (Chapter 4). However, there were no mean improvements in any of the cognitive tests throughout the 4 wk intervention
period. It is possible that the dose of MT was still not substantial enough to elicit an improvement in cognitive function in the rugby union players. However, similar studies have been conducted in clinical and healthy populations, with interventions of varying length and frequency, revealing positive influences of mindfulness training on cognitive performance (A. Chiesa et al., 2011). Moreover, very brief mindfulness interventions have also improved cognitive performance. For example, Tang et al. (2007) implemented a 5-d, 20-min/day intervention in forty university students and showed a significant increase in executive attention scores on the Attention Network Test. It is also possible that the cognitive test battery was not sensitive enough to highlight potential changes in cognitive function evoked by MT and that a sport-specific cognitive test may have been more likely to highlight changes due their ecological validity (Ali, 2011). Nevertheless, the CogState battery was chosen due to its established retest reliability in team-sport athletes (Chapter 2), whereas, the reliability of sport-specific cognitive tests is questionable due to sample heterogeneity (Atkinson & Nevill, 1998), potential habituation, and/or performance being determined by subjective opinion (Ali, 2011).

Although the results of our third experimental study (Chapter 4) showed no effects of MT on cognitive function, previous researchers have demonstrated the positive influences of MT on other determinants of sports performance. These include improved coach’s performance ratings (Lutkenhouse et al., 2007), increases in ratings of experiential acceptance, dispositional flow, and mindfulness attention (Schwanhausser, 2009) and improvements in national ranking (M. Bernier et al., 2009). In clinical research, there is also evidence that MT can reduce stress in cancer sufferers, with results indicating reductions in both plasma- (Witek-Janusek et al.,
2008) and salivary- (Carlson et al., 2004; Matousek et al., 2011) cortisol levels following completion of MT interventions. In addition, MT has been shown to improve mucosal immune function, with an increase in sIgA in healthy university students (Fan et al., 2010). However, it was unknown whether MT could positively affect stress-related changes in cortisol and immune function (sIgA) in athletes. We wanted to explore this, as we hypothesised that MT may have the potential to help athletes manage stress and maintain healthy immune function during periods of competition.

Before we could explore the effects of MT on sCort and sIgA in teams-sport athletes, it was important to select a salivary analysis system that could not only reliably measure sCort and sIgA under repeated conditions, but was efficient with respect to delivering results. ELISA has been considered the ‘gold standard’ saliva analysis procedure (Fahlman & Engels, 2005; Gleeson et al., 1999), however, its experimental procedures are comprehensive and time-consuming, and therefore may not be optimal for the applied sport science environment. The IPRO system is efficient and easy to use, however, prior to this thesis, acceptable reliability for determining sCort and sIgA had only been established at immediate retest intervals (Coad et al., 2015; Fisher et al., 2015). Considering the longitudinal changes in sCort and sIgA typically associated with training and/or competition, the establishment of inter-day reliability was paramount. In addition, it was unknown whether the IPRO was reliable in its ability to detect the change in sCort and sIgA observed in response to maximal exercise. Data from Chapter 5 demonstrated the IPRO to be a reliable measure of determining sCort and rate of sIgA secretion at rest and after sprint cycling-exercise. Resting and post-exercise sCort and rate of sIgA secretion were not different when
comparing the two trials. We also demonstrated the IPRO to be sensitive to high-intensity-exercise responses in sCort and rate of s-IgA secretion. sCort increased while rate of sIgA secretion decreased, in both trials, following completion of the 2xWAnT. These findings are in agreement with previous studies that have reported an increase in sCort (Hayes et al., 2015; Kraemer & Ratamess, 2012) and a decrease in sIgA (Fahlman et al., 2001; Nieman et al., 2002) following high-intensity exercise. The performance and physiological variables from the WAnT (mean power, peak power, mean cadence, peak HR, blood lactate) also displayed values that are considered within the commonly reported reliability criteria previously mentioned (Hopkins, 2000). Therefore, future researchers, sports scientists and coaches can be confident that any acute or chronic changes observed in sCort or rate of sIgA secretion, as determined by the IPRO, are meaning of an external factor (i.e., acute exercise, chronic training loads etc.).

Due to the findings of experiment 4 (Chapter 5), the final experiment of this thesis (Chapter 6) investigated whether 8 wk of MT could alter changes in resting sCort and rate of sIgA secretion that are associated with competition in a team of highly-trained wheelchair-basketball players. The results showed that 8 wk of MT had no effect on rate of sIgA secretion in the wheelchair basketball players. Any changes observed in rate of sIgA secretion in the Mindful group, throughout the intervention period, were also observed in the Control group. It is likely that the competition period was not intense enough to elicit a decrease in mucosal immune function. Actually, the competition period is the likely cause of the increase in rate of sIgA secretion. This is supported by Gleeson et al. (2000) who observed an increase in salivary sIgA concentrations during a final, 12-wk training cycle prior to the national swimming
championships. Nevertheless, any increases in rate of sIgA secretion that may have been caused by the mindfulness training did not exceed the increases elicited by the competition period.

We observed an increase in sCort in the Control group that remained elevated in response to the Competition period. This finding is typical of cortisol behaviour in response to increases in training load or competition (Kirwan et al., 1988; Urhausen et al.). In contrast, sCort increased in the Mindful group for only a brief amount of time (from MT-BL to MT-wk2) and returned to concentrations no different to MT-BL, at MT-4wk, for the remainder of the intervention period. It is possible that MT caused beneficial neurological effects in the Mindful group by inhibiting the stress-related increase in basal sCort, caused by the ongoing demands of the competition period that was seen in the Control group. This statement is supported by evidence that mindfulness training is associated with increased cortical and thickness and gray matter density in the Anterior Cingulate Cortex (Grant et al., 2010) Insula (Hölzel et al., 2011; Hölzel et al., 2007; Lazar et al., 2005), and areas of the Prefrontal Cortex (Hölzel, et al., 2007); regions of the brain associated with the cognitive mechanisms attention regulation, body awareness and emotion regulation, respectively. In addition, a review by Hölzel et al. (2011) reported that the aforementioned mechanisms work synergistically to develop increased self-regulation. Furthermore, Farb et al. (2010) observed greater ventro-lateral Prefrontal Cortex activity, in participants after completing 8 wk of MT. Authors reported this augmented a top-down inhibitory effect on the amygdala that is responsible for fear appraisal, emotional reaction and initiation of the hypothalamic-pituitary axis (Urry et al., 2006). Therefore, it can be postulated that MT was associated with increased neural
activity, in the Mindful group, in brain areas aforementioned that resulted in an attenuation of their stress response during the Competition period. Therefore, MT may be a useful recovery tool to manage the onset of physiological stress in athletes during competition.

7.2 Thesis limitations

The main limitation from this thesis relates to the CogState cognitive test battery; we believe the tests may not have been sensitive enough to highlight potential changes in cognitive function evoked by the mindfulness training intervention. The cognitive tests chosen (i.e. DET, IDN, OCL, GMLT) to assess cognitive performance in experiments 2 and 3 have been designed to measure the fundamental cognitive skills of psychomotor function, vigilance, visual learning and memory, and executive function, respectively. Though, in sporting research, similar cognitive tests have been criticized for their lack of ecological validity (Ali, 2011). In addition, there is conflicting evidence concerning their ability to differentiate competition level in athlete groups (Castiello & Umiltà, 1992; Helsen & Starkes, 1999). However, a meta-analysis by Voss et al. (2010) has highlighted the relevance of such tests as having “important implications for capturing and characterising the fundamental cognitive skills associated with competitive sport training.” Previous studies have implemented cognitive tests that present images (McMorris & Graydon, 1996), models (McMorris & Graydon, 1997), or videos (Williams & Davids, 1998) to simulate sport-specific gameplay situations for the assessment of decision-making ability and visual behaviours. It is unknown whether a sport-specific cognitive test would have highlighted potential changes elicited by the MT intervention, had such a test been
implemented in the second (Chapter 3) and third (Chapter 4) experimental chapters of this thesis. Nevertheless, the CogState battery was chosen for those experiments because of: i. its ability to measure fundamental aspects of cognition (i.e. psychomotor function, vigilance, visual learning and memory), and ii. our ability to establish its retest reliability with highly-trained athletes in experiment 1. Whereas, the reliability of sport-specific cognitive tests is questionable due to sample heterogeneity (Atkinson & Nevill, 1998), potential habituation, and/or performance being determined by subjective opinion (Ali, 2011).

In addition, a limitation of Experiment 2 (Chapter 3) and Experiment 3 (Chapter 4) were the small sample sizes. Indeed, larger sample sizes may have resulted in different results, as power estimates ranged from 0.30 – 0.97 for the primary dependent variables in Experiment 2 and 0.30 – 0.50 for those in Experiment 3 not to be found significantly different from baseline to post intervention. However, due to the nature of elite sport, low sample sizes are often observed in sporting research (Secomb et al., 2016; Veness et al., 2017). Nonetheless, despite the low statistical power, Biau, Kerneis and Porcher (2008) have highlighted the importance of identifying what can considered a ‘meaningful’ change in the dependent variable. In addition, Hopkins (2004) has reported that, in elite sport, athletes and coaches would be ‘reasonably confident of a worthwhile change’ where an increase in half the typical error of the dependent variable is observed. Hopkins (2004) also recommends that athletes should aim to improve by double the typical error of the dependent variable. A study by MacDonald and Minahan (2016) demonstrated what would be considered a ‘worthwhile change’ in performance of the CogState test battery. For example, given the typical error of 4.2% for mean speed on the Detection Task, coaches and
athletes would be ‘reasonably confident of a worthwhile change’ (Hopkins, 2004) where an increase in mean speed of 2.1% (i.e., half the typical error) or 6 ms is observed. In addition, athletes should aim to improve by double the typical error (Hopkins 2004; i.e., 8.4% for mean speed), or 25 ms, from an initial mean speed of 294 ms. Considering the recommendations made by Hopkins (2014) and the findings of MacDonald and Minahan (2016), any observed improvements in the cognitive performance variables in the Mindful group, that were not also observed in the Control group, were not great enough to be considered a ‘worthwhile change.’ Therefore, it is reasonable to suggest that the mindfulness training had no significant effect on cognitive performance in the rugby union players.

Another limitation to this thesis must be noted from the third experimental study (Chapter 4); it is possible that 4 wk of MT was not substantial enough to elicit an improvement in cognitive function in the rugby union players. However, similar studies have been conducted in clinical and healthy populations, with interventions of varying length and frequency, revealing positive influences of mindfulness training on cognitive performance (Chiesa et al., 2011). Furthermore, the intervention was chosen as it could be implemented into the sporting group without hindering the current individual as well as team training and coaching procedures. If time permitted, we would have preferred to extend the intervention period for this training study to ~8 wk, similar to that used in experiment 5 of this thesis. Nevertheless, during the process of identifying optimal doses of MT, it is important to identify doses that are ineffective to avoid their potential implementation in sporting team.
7.3 Practical applications

- This thesis demonstrated the CogState battery to be a reliable measure of cognitive performance in athletes. This outcome will enable sport scientists and coaches to implement CogState, wholly, or in part, to assess fundamental indices of cognition (i.e., psychomotor function, vigilance, visual learning and memory) in their athletes, for performance or research purposes, and be confident that a change in performance is representative of an external factor (i.e., supplementation, exercise etc.) and not attributed to biological or measurement noise.

- The IPRO method can now be used in both the sporting realm and future research to determine sCort concentration and rate of sIgA secretion. Sport scientists and coaches can be sure that the IPRO is sensitive in detecting a change sCort concentration or rate of sIgA secretion that may be elicited by either an acute stimulus (i.e. sprint cycling) or chronic effect (i.e., training load, competition etc.). The IPRO method will prove to be valuable on-field, at training facilities and in sport science laboratories as it is easy to administer and time-efficient.

- A 20-min mindfulness meditation session does not alter cognitive performance of a computer based test battery; nor does a 4 wk MT intervention (3 x 20-min-wk$^{-1}$). Although there were no significant results, these results will appeal to scientists, sport psychologists and coaches who are considering MT dosage for their athletes. They should be aware that shorter doses of MT might not be effective in improving fundamental aspects of cognition in their athletes.
• Coaches and athletes should consider the implementation of MT as a regular training procedure. Regular practice (i.e., 5 x 30min·wk⁻¹) of MT may help athletes better manage stress during periods of increased training load or competition. If MT can attenuate increases in sCort, MT may prevent the risk of athletes becoming overreached and reduce the prevalence of overtraining syndrome.

7.4 Future considerations

The results of this thesis highlight the need to explore optimal doses of MT that may elicit an improvement in cognitive function in team-sport athletes. However, it must be considered that the ‘optimal dose’ of MT for team-sport athletes may well be ill-defined; it is likely to differ between sporting disciplines due to the differences in both on- and off-field demands. Nonetheless, considering this thesis only explored a brief meditation session (20 min) and a 4 wk intervention, there is potential to evaluate the efficacy of much longer MT interventions (i.e. 8 wk, an entire competitive year etc.) in their ability to evoke changes in cognitive function.

In addition, this thesis explored one cognitive test battery (CogState) and its ability to assess the cognitive domains of executive function (Groton Maze Learning Task), psychomotor function (Detection Task), vigilance (Identification Task), visual learning and memory (One Card Learning Task) and the changes that may be associated with MT. There are still many other neurocognitive tests available that may be more sensitive to detect changes associated with MT and therefore, need to be
investigated to determine whether MT may improve other aspects of cognitive function in team-sport athletes.

Indeed, Experiment 5 (Chapter 6) demonstrated that MT can attenuate increases in resting sCort associated with competition. But there are still several other ways that MT may be useful in attenuating the onset of stress during competition (i.e., diurnal patterns in cortisol secretion following a match) and need to be investigated. Furthermore, 8 wk of MT did not elicit a change in the chronic resting rate of sIgA secretion in the wheelchair-basketball players, but it may have an effect on the acute response to high-intensity training and/or a game.

Finally, this thesis focused on the effects of MT on cognitive function, stress and mucosal immune function in team-sport athletes. Nevertheless, research in the area of MT and sports performance is still very scarce. Therefore, this leaves great potential for future research opportunities and how MT may further enhance athletic performance.
7.5 Conclusion

Mindfulness training is an intervention whereby, with practice, individuals can develop an ability to be aware of their own mental activity in the present moment, while maintaining control over a chosen focus of attention. In sport, MT provides athletes with a self-regulatory process that may help them deal with the multitude of challenges that are innate in elite or high-level competition. Possessing the ability to objectively reappraise those challenges will thereby enable an athlete to interrupt their own psychological re-activity and concomitant increases in their own physiological stress response. While this thesis provides advancements in the understanding of MT in sport, the body of research surrounding it is very much still in its infancy. Nonetheless, this hosts for an exciting future for research in this area and the implications for MT in elite sport.
References


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List of symbols and abbreviations

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<thead>
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<tr>
<td>°C</td>
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