THE PSYCHOPHYSIOLOGICAL EFFECTS OF A DUAL TASK, TASK DIFFICULTY, AND PRESSURE ON SKILLED MOTOR PERFORMANCE

BY

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ABSTRACT

This thesis aimed to explore the psychophysiological effects of a dual task, task difficulty, and pressure on skilled motor performance. More specifically, how preparatory cardiac activity in the seconds preceding performance may be indicative of attentional processes, and whether isolated pressure manipulations have equal effects. Firstly, the combined results of this thesis demonstrate that depending on the pressure applied, different psychophysiological responses may be exhibited. Thus, pressure may not have equivalent effects. Secondly, a novel self-report measure which assesses attentional focus from a more multi-dimensional perspective is presented. Finally, heart rate deceleration was established in two previously explored contexts and one novel task. Pre-performance cardiac activity was found to differ as a function of task difficulty and pressure. Experts were shown to exhibit heart rate deceleration during characterisation of a full golf swing - a more physically demanding task than has been previously explored. However, in contrast to existing findings, intermediate golfers did not. These results are discussed in the context of further support for the relationship between attention processes and preparatory bradycardia in relation to expertise, performance, and self-focus theories of choking. Unlike previous literature, which implied the magnitude of bradycardia may be important for skilled motor execution, the rate of heart rate deceleration proved to be the best correlate of performance. A new model of the rate of heart rate deceleration indicating attentional efficiency is presented as a result.

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LIST OF PUBLICATIONS

Data from this thesis led to the publication of the following conference abstracts:

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CHAPTER ONE

General Introduction

Skilled motor performance is synonymous with fine motor control. Optimal attentional processes are regularly associated with successful performance outcomes in sports such as golf, darts, and shooting, where accurate planning, programming, and movement control is integral to skill execution (Abernethy *et al*., 2007; Wulf, 2007). Furthermore, the ability to maintain these processes during competition, particularly when under pressure, continues to be a main source of interest for the academic and practitioner community. Despite research-practitioners having developed several effective mental skills practices to support athletes maintaining optimal performance under pressure (see Locke & Latham, 1990; Singer *et al*., 1993; Vealey, 2007), these methods are often reliant on observations, subjectivity, and self-report data. Psychophysiology could provide a more objective measure of performance processes (Abernethy *et al*., 2007; Collins, 2002), such as attentional focus.

As defined in a recent special issue of Sport, Exercise, and Performance Psychology, '*Psychophysiology is the scientific study of the reciprocal relations between mind and body*' and '*it is characterised by interdisciplinary, multi-measure research studies, which shed light on the processes and mechanisms underpinning human behaviour*' (Cooke & Ring, 2019). Although this discipline has progressively grown in appeal since its conception in the mid-20th century, the total number of studies in this area remains a small percentage of the wider domain. However, technological advancements, particularly in the field of wearable products, means the accurate collection of concurrent physiological and psychological data is becoming ever more insightful in the context of successful sports performance.

For instance, the exploration of performance under pressure and the development of associated conceptual frameworks involving attentional processes, has attracted much interest in recent decades.

An overview of related constructs is provided below. However, given the increasing scrutiny of methodological rigor (Larson & Moser, 2017) and ever greater desire for objectivity, it is surprising that psychophysiological protocols remain relatively underutilised. This thesis therefore sought to contribute to the literature described below from a psychophysiological perspective.

Attentional Processes

Focus of attention in relation to performance has generated much intrigue from the academic and performance sport communities, as it has long been regarded as an influential factor for success. Attentional focus has been considered from varying perspectives. For example, Morgan (1978) and Weinberg *et al*., (1984) explored the difference between associative or dissociative attention i.e., focusing on bodily sensation rather than blocking out feelings associated with physical effort. Width and direction were terms used by Moran (1996) to describe broad versus narrow, and Nideffer and Sagal (1998) to describe internal versus external focus of attention. Whilst attentional focus must work synergistically with other performance processes to create a state of optimal cognition for skilled motor control, generally external focus appears to be more beneficial than internal focus. Wulf *et al*., (1998) first defined external focus as how individuals can direct attention towards the effects their movements have on the environment, whilst internal focus was suggested to indicate greater attention on the performers own body movements. According to Wulf (2013), about 80 studies have determined significant advantages of external focus of attention compared to internal focus of attention. Strikingly, no study included in Wulf’s (2013) review article found internal focus of attention to have advantageous effects. As such, the effects of external focus of attention on performance and skill acquisition are reviewed below, and the constrained action hypothesis is then summarised and presented as the main model of directional focus of attention.

Performance

Whilst a variety of studies have looked at the influence of external focus of attention on performance elements such as balance (Wulf *et al*., 1998), maximum force production (Marchant *et al*., 2009), generation of speed (Freudenheim *et al*., 2010), and endurance capabilities (Porter *et al*., 2010), for the purpose of this thesis I will review the literature relevant to skilled motor performance. For instance, external focus of attention has been found to improve performance in golf when participants have been asked to focus on either the movement of the club (Wulf *et al*., 1999), the clubface, or the intended ball trajectory (Bell & Hardy, 2009), in comparison to how their body moves. These results have been extended to include a golf skill requiring finer motor control - golf putting. Granados (2010) found that performance accuracy improved when focus was directed to the movement of the putter rather than movement of the hands. Furthermore, these results seem to be relative for novice and experienced performance. Bell and Hardy (2009) determined that external focus instructions enhanced performance in experienced golfers compared to the internal focus group. This study along with a throwing task investigated by Ong *et al*., (2010), also demonstrate how automaticity resulting from external focus appears to help performers maintain skill under pressure. Outside of golf, performance has been found to improve in basketball free-throws (Zachry *et al*., 2005) and dart throwing (Lohse *et al*., 2010) when focus was directed towards the target, rather than how the body moves, or proximal focus points.

These two latter studies (Lohse *et al*., 2010; Zachry *et al*., 2005) also assessed muscle activity through electromyography (EMG). EMG was found to be reduced in muscle sites implicated with successful performance, namely, the triceps in dart throwing, and biceps and triceps brachii in basketball free-throws. These findings suggest that external focus of attention is not only associated with enhanced performance, but performance may be improved by more accurate force production. Accordingly, movement kinematics akin with more successful performance may also be influenced by external focus. For example, Ford *et al*., (2009) found greater displacement of various joints implicated in football kicks in participants who were given internal focus instructions. Contrastingly, in response to being asked to focus on the ball trajectory, the external focus group displayed a more successful pattern of movement. Similarly, Lohse *et al*., (2010) found external focus of attention to positively impact shoulder angle at the moment of release in dart throwing. Another study by An *et al*., (2013) used the X-factor in golf to assess a more complex pattern of movement. In essence, the X-factor is an important contributor to carry distance and refers to the rotation of the shoulders relative to the pelvis. External focus of attention produced higher maximum angular velocities of the pelvis, shoulder, and wrist, which along with a greater increase in X-factor during the downswing, resulted in more carry distance compared to the internal focus group. In combination, these studies demonstrate that performance outcome, muscular activity, and movement patterns can be enhanced by external focus of attention.

Despite the large percentage of studies in this area advocating the benefits of external focus of attention on performance, some studies have found contradictory results. In juggling, Zentgraf and Munzert (2009) found that ball throw height was more consistent with external focus instructions, but that joint displacement was better for performance in response to internal focus instructions. Perkins-Ceccato *et al*., (2003) determined that golf performance was less variable for the internal focus group than the external focus group. Equally, Lawrence *et al*., (2011) argued that external focus instructions might not be appropriate for complex patterns of movement such as gymnastics routines. However, these contradictory findings can all be scrutinised in relation to the attentional instructions. Taken together, these studies could be considered to have applied ambiguous, incorrect directional, and too many attentional instructions. In light of these potential methodological limitations therefore, the evidence suggesting external focus of attention is beneficial for performance remains convincing.

Skill Acquisition

Fitts and Posner’s (1967) classic definition of learning is inherently linked to external focus of attention being beneficial for performance. According to this model, novices are generally deemed to exhibit processes associated with early stages of learning (declarative), which describes the conscious control of movement and explicit encoding of knowledge. Experts are conversely considered to engage in external cues and environmental information as movement planning and programming is more automatic. In essence, this learning paradigm suggests that internal focus will be more prevalent for novice performers, whilst experts are more likely to engage in external focus of attention (Anderson, 1982). Beilock *et al*., (2004a) confirmed these patterns experimentally use golf putting. Novice performance was enhanced by conditions which facilitated on-line attentional monitoring (i.e., where internal focus of attention was allowed to influence motor control planning, programming, and execution), compared to conditions which were designed to prevent explicit attentional control of skill execution. In contrast, experts performed better in conditions which limited attention to execution (i.e., where they could perform more automatically based on external focus of attention). Furthermore, studies have found that experts are unable to recall details about performance, which again suggests greater automaticity and reliance on external cues during skill execution (Beilock & Carr, 2001; Ericsson, 2006).

Not only is external focus of attention considered a characteristic of expertise, adoption of this type of attentional focus during skill acquisition has also been shown to accelerate learning. For instance, Maddox (1999) found tennis backhand accuracy to be better in response to external focus of attention instructions at acquisition, retention, and transfer stages of the experiment. Wulf *et al*., (1998) similarly determined that in learning a slalom-type movement on a ski-simulator under external focus instructions, participants exhibited signs of enhanced learning compared to an internal focus and control group. Moreover, the internal focus group did not record any beneficial learning effects compared to control. In football, Zachry *et al*., (2005) found that accuracy of kicking improved when participants were asked to direct their attention to the part of the ball they needed to strike (external) as opposed to the part of their foot they would need to kick with (internal). Parr & Button, (2009) extended these findings to include analysis of movement kinematics in rowers. Novice individuals displayed greater improvements in technique when asked to ‘keep the blade level during the recovery’ (external focus) compared to ‘keep your hands level during the recovery’ (internal focus). The external focus group demonstrated a shorter time and distance to lock (i.e., from maximum reach to the blade being fully immersed) on retention and transfer tests. In the context of sports performance, coaching is often reliant on feedback to help athletes reflect, understand, and implement changes regarding technique and performance. Performance outcomes in volleyball serves, football kicks (Wulf *et al*., 2002), and football throw-ins (Wulf *et al*., 2010) have all been determined to be more accurate when participants were given feedback that promoted external focus of attention rather than internal attentional processes. In summary, these results indicate that external focus of attention is beneficial for performance and efficient movement patterns when learning a new skill.

In contrast to this overwhelming positive view in favour of using external focus of attention during skill acquisition, Emanuel *et al*., (2008) found no effect of attentional instructions on dart throwing performance. Nevertheless, the lack of comparability in terms of instructional groups and number of instructions could have affected results validity. Alternatively, it has been argued that this persuasive evidence undermines learning paradigms, which suggest internal focus may be beneficial and required in early stages of learning (Fitts & Posner, 1967). This notion is frequently supported by studies which show novices perform better when their attention is focused on the skill rather than shared with a secondary task in a dual-task protocol (Beilock *et al*., 2004a; Beilock *et al*., 2002; Gray, 2004). However, these studies commonly do not define or provide a consistent operational explanation for how focus on skill is achieved, and furthermore, instructions used to induce skill focus have varied in terms of whether they are likely to induce external of internal focus. Importantly, these studies also do not directly compare internal and external focus of attention. Arguably, both internal and external focus instructions can relate to skilled performance. Therefore, the fact that novice participants perform better when focused on the task in hand rather than a secondary task is perhaps unsurprising.

Constrained Action Hypothesis

To encapsulate the findings associated with external focus of attention, Wulf and colleagues developed the constrained action hypothesis (Wulf *et al*., 2001a). This model suggests that conscious control is induced by internal focus of attention, because automatic control processes are impeded by the constraint of the motor systems. External focus of attention contrastingly utilises unconscious, fast, and reflective control processes to promote automaticity. Empirical evidence has demonstrated a relationship between the measure of automaticity and instructing participants to focus their attention externally. For instance, one study examined reaction time whilst participants performed a dynamic balance task after been given external or internal focus instructions (Wulf, *et al*., 2001b). Using a dual task methodology to assess the amount of attention required to perform the primary task, this study found that external focus resulted in more effective balance, more efficient learning, and a quicker reaction time. Overall Wulf *et al*., (2001b) suggested that external focus of attention helped participants achieve automaticity sooner, and the retention of skill in the external instruction group represented a learning effect. Lohse (2012) similarly used a force production task to determine that external focus instructions resulted in participants exhibiting reduced pre-movement times compared to an internal focus group. This result implied that external focus of attention results in more efficient motor planning, which again, suggests a shift toward greater automaticity. Another study analysed the frequency of movement adjustments in relation to external and internal focus instructions (Wulf *et al*., 2001a). Under the premise that faster movement adjustments reflect use of automatic reflexive feedback loops, and slower adjustments indicate utilisation of more conscious feedback loops, power spectral analyses of balance tasks were employed to determine the dominant frequency components of movement patterns. The external focus group were found to make more frequent and smaller corrections to help maintain balance in comparison to the internal focus group. Moreover, in a similar study by McNevin *et al*., (2003), the display of higher frequency adjustments in participants who were asked to focus on markers that were further away from their feet, were more pronounced than those who focused on markers close to their feet in a balance task. In combination, these latter two studies suggest that automaticity is increased when participants are given external focus instructions, and that the effects are greater when the focus point is further away from the body.

Whilst these results offer support in favour of the constrained action hypothesis, some criticism exists. For example, it does not integrate with larger theories of motor learning and control (Oudejans *et al*., 2007) and it does not specify the precise mechanisms that constrain action (Raab, 2007). In response to these considerations, Wulf and Lewthwaite (2010) expanded the constrained action view to include mention of ‘self-invoking triggers’. This additional mechanistic element suggests that internal focus may result in performers unconsciously accessing neural representation of the self, and essentially describes reinvestment theory (Baumeister, 1984), which is discussed later in this chapter. Self-evaluative and self-regulatory processing are resultantly activated. Incidences such as this can influence thought, actions, and behaviour (e.g., Bargh & Morsella, 2008) and potentially result in ‘micro-choking’ episodes which may ultimately lead to performance detriments. In summary, the constrained action hypothesis is a well-established conceptual framework for describing the benefits of external focus of attention. Although this updated view may help elaborate and specify mechanistic effects, further consideration around how this theory may delineate relative contributions of explicit and implicit learning, and interact with attentional processes related to choking under pressure is required. Psychophysiological methods as presented in this thesis may help further understanding from this perspective.

Performance Under Pressure

Performance under pressure is synonymous with sport. Whilst examples of sporting excellence regularly adorn the front pages of media publications, empirical (e.g., Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992) and anecdotal (e.g., Rory McIroy in 2011 U.S. Masters golf tournament, the England Senior Men’s Football Team in major tournament penalty shoot-outs, Jimmy White at the 1994 World Snooker Final) evidence suggests that athletes can experience a decline in performance when the stakes are high. Pressure can stem from *‘any factor or combination of factors that increases the importance of performing well on a particular occasion’* (Baumeister, 1984), but in sport, there is strong agreement that the desire to succeed can elicit pressure to perform (Beilock & Carr, 2001). The process of not being able to maintain performance in the face of pressure is called choking (Beilock & Gray, 2007). In skilled motor performance, attentional processes are implicated in the breakdown of performance under pressure (Baumeister, 1984; Eysenck and Calvo, 1992; Masters, 1992). Despite performance under pressure having received much attention from the academic and professional sports community, uncertainty remains regarding the effects of pressure. The following sections outline current understanding of how pressure might affect performance, physiological measures, and attentional processes.

The Effects of Pressure

Pressure is often deemed greatest in elite sport, where the rewards and consequences linked to performance outcome are generally at their most extreme. However, under Baumeister and Showers (1986) broad and situational definition of performance (i.e., an individual can be termed as 'performing' whenever they carry out a task in a situation which requires an optimal outcome), all skill levels are susceptible to choking. Within the literature, it is widely accepted therefore that pressure can detrimentally affect performance (Hill *et al*., 2010). For instance, Oudejans (2008) found handgun shooting performance significantly declined when police officers faced an opponent who fired back (high pressure), compared to a cardboard figure (low pressure). Similarly, Wilson *et al*., (2006) showed that driving performance was negatively impacted when participants were exposed to ego-threatening instruction and given the opportunity to win £50. Moreover, Williams *et al*., (2002) found that table tennis performance worsened under evaluative competitive pressures. Lewis and Linder (1997) claimed to have observed choking when performance deteriorated by 2.6 cm per trial in an 80 cm golf putting task under pressure. Experienced golfers were similarly found to suffer from performance deterioration under pressure from a greater distance of 3 m in a more recent study by Gucciardi and Dimmock (2008).

Ecologically, pressure often occurs in competitive sporting scenarios (Baumeister & Showers, 1986; Martin & Hall, 1997). In contrast to the perspective presented above, which suggests pressure can impair performance, competition has been found to have both facilitative and debilitative effects. For example, in a meta-analysis of sixty-four studies, Stanne *et al*., (1999) found competition to enhance performance compared to individualistic "do your best" situations. Furthermore, previous work has shown that individual sports generally evoke greater pressure than team sports (Martin & Hall, 1997), but that ego-threat may have the potential to induce choking when performers are faced with an individualistic scenario that could directly affect teammates (Baumeister, 1997). In terms of skilled motor tasks, competition has been found to improve performance in skills that are simple or well learned, but can impair performance when tasks are complex or not well learned (Martens, 1975).

Studies which aim to replicate the effects of pressure in a laboratory environment, often to do so by manipulating the task, the performer, and/or the environment. For instance, two studies led by Stoker (Stoker *et al*., 2017, 2019) manipulated task difficulty by altering target size, distance from target, and randomised versus block task completion. Similarly, Oudejans and Pijpers (2009) induced environmental pressure by increasing the height where participants performed a dart throwing task from, whilst Driskell *et al*., (2001) used sound to induce pressure through noise distraction. Although performers can be manipulated by impacting normal physiological and/or psychological function e.g., inducing fatigue though pre-performance tasks, such as the Stroop Test (Provost & Woodward, 1991), a significant amount of research chooses to manipulate psychological processes by introducing performance contingent consequences (either positive or negative). As part of wider interventions, rewards, punishment, and evaluation have all been used to increase pressure (e.g., Bell *et al*., 2013; Driskell *et al*., 2014; Oudejans & Pipers, 2009, 2010; Stoker *et al*., 2017, 2019). Specific examples of increasing pressure through the introduction of a negatively perceived consequence, include the threat of cleaning a changing room (Bell *et al*., 2013) or participating in a staged media conference (Stoker *et al*., 2019). Greater pressure has also been reported where evaluation from a peer and/or coach may be received (Driskell *et al*., 2014), regardless of whether the evaluation takes place in person (i.e., audience) or remotely through video recordings (Mesagno *et al.*, 2011). Research which has used rewards-based consequences to manipulate pressure, commonly feature performance-contingent monetary incentives (Belilock & Carr, 2001; Masters, 1992, Oudejans & Pijpers, 2009).

Above and beyond performance data, there is a growing trend towards obtaining a greater understanding of how pressure affects physiological and kinematic measures. For example, it is generally assumed that high pressure situations can evoke anxiety (Staal, 2004) and that heart rate (HR) increases with anxiety through the autonomic nervous system. As such, HR can provide an objective measure of increased pressure in skilled motor tasks (Åstrand *et al*., 2003). Cooke *et al*., (2010) found HR to increase in response to a high (performance-contingent monetary reward or punishment associated with each trial) and medium (leader board with 10% possibility of winning a financial reward) pressure condition. Similarly, Veldhuijzen van Zanten *et al.,* (2002) determined HR to increase during competition, whilst Carroll *et al*., (1986) observed a higher HR in participants when task difficulty increased. Heart rate variability (HRV) has also been used as a measure of anxiety and greater effort. Generally assessed in low (0.02-0.06 Hz), mid (0.07-0.14 Hz), and high (0.15-0.50 Hz) frequency bands (Mulder, 1992), changes are influenced by the sympathetic and/or parasympathetic systems which are implicated in physiological responses to anxiety. Cooke *et al*., (2010) showed that SDNN (the standard deviation of R-R intervals), a correlate of the mid-frequency band (Carrasco *et al*., 2001) which has been linked to mental effort (Mulder, 1992), increased with high pressure.

Muscle tension is another measure which has also been found to be affected by anxiety (e.g., Duffy, 1932). Through EMG, Weinberg and Hunt (1976) determined that participants who experienced high levels of anxiety, contracted their biceps and triceps for longer in a tennis ball throwing task compared to a low anxiety group. Likewise, Cooke *et al*., (2010) found that performance worsened, and muscle tension increased in muscle groups implicated in successful putting stroke movements under high pressure. Movement kinematics have been similarly suggested to be negatively influenced by pressure (Cooke *et al.*, 2010, 2011; Pijpers *et al*., 2005; Nieuwenhuys *et al*., 2008). For example, Cooke *et al*., (2010) found that along with increased muscle tension, novice participants missed putts under high pressure because lateral clubhead acceleration increased. Maxwell *et al*., (2003) also explored the kinematic effects of pressure in golf putting, and found that the putting stroke became less accurate as a result of the back and forth movements becoming more jerky and less smooth under pressure. However, Mullen and Hardy (2000) observed no effects on putting stroke kinematics following two-dimensional analysis (both club and arm movement) in response to pressure. Outside of golf, climbers have been found to adapt their movement pattern to exhibit longer-lasting reaching movements, meaning it took longer for them to transverse a wall under pressure (Pijpers *et al*., 2005; Nieuwenhuys *et al*., 2008).

Although these studies reflect the variety of potential effects pressure may have on athletes in a performance context, under the assumption that pressure has equal and additive effects (Baumeister, 1984), many experimental protocols with similar conclusions have employed different pressure manipulations. The different manipulations employed arguably represent distinct nuances of pressure research, but ease of application and ecological relevance are often the main considerations in methodological design. The protocols used to induce pressure are understandably normally further rationalised by addressing the suitability of a manipulation to explore specific hypotheses and the validation offered by existing literature. For example, Mesagno *et al*., (2011) induced pressure by filming participants under evaluative pretences to explore self-presentation and choking, as heightened self-consciousness was likely to be a manipulative effect. Whereas Wilson *et al*., (2006), described selecting ego-threat as the high-pressure condition because previous studies had found it to be a successful way of inducing pressure before task completion. Moreover, to ensure an increase in pressure is achieved, manipulations are often used in combination (Cooke *et al*., 2010, 2011, 2014) and as part of a wider experimental protocol (Bell *et al*., 2013). These inconsistencies mean a fundamental lack of clarity remains as to whether isolated pressure manipulations cause equivalent effects.

Recent literature has begun to challenge Baumeister's (1984) perspective on the equivalence of pressure by exploring how different isolated pressures affect performance. Mesagno *et al*., (2011) employed a series of manipulations based on evaluation and monetary rewards to induce pressure in a field hockey task. Performance was found to decline in groups that were exposed to themes of self-presentation, but improvements were recorded in the performance-contingent monetary incentive and video-camera placebo groups. Meanwhile, Stoker *et al*., (2017) observed that isolated pressure conditions involving consequences (e.g., evaluation, reward, and forfeit), resulted in significantly higher levels of pressure compared to a control condition, but performance only worsened when a task or environmental constraint was introduced (e.g., occlusion goggles, time constraint, and noise distraction). Conversely, although Stoker *et al*., (2019) confirmed that consequences were crucial for inducing pressure in a follow up study, the forfeit condition actually corresponded to a performance improvement when compared to the condition where participant's psychological ability was manipulated (cognitive pre-fatigue induced by Stroop test). In elite netballers, isolated consequence-based pressures and combined consequence and task manipulation pressures, were found to induce a higher HR compared to control, whilst isolated conditions where the task was manipulated were found to have no effect on HR (Stoker *et al*., 2017). In combination, these preliminary studies begin to support the notion that different isolated pressures do not produce equal effects.

Theories of Choking Under Pressure

In skilled motor performance, choking under pressure is most commonly explained by attentional mechanisms. Divided into distraction and self-focus theories, disruption of attentional processes is thought to be influential in the breakdown of skill. Distraction-based model advocates (DeCaro *et al*., 2011) propose that performance decreases because attention becomes focused on task-irrelevant thoughts. Resultantly, working memory becomes overloaded with worries about consequence or demands associated with the task, which then interferes with the attention required to perform skilfully. Processing efficiency theory (Eysenck & Calvo, 1992) is an established distraction theory which suggests that performance will be affected by inefficient processing, unless athletes are able to mobilise effort. However, when pressure exceeds a limit where anxiety and/or completion of a cognitively demanding task under pressure becomes overwhelming, the protective effects of effort may be unable to maintain performance, and instead, exceeding attentional capacity limits can lead to incidences of choking.

Based on Baddeley's (1986) tripartite model of the working memory system, the main effects of anxiety are on the central executive component of working memory which is responsible for self-regulatory functions and active processing. As a result of pressure, attentional capacity within the central executive can become consumed through anxiety induced worry. When this occurs to the point where no auxiliary resources remain to retain on-task attention, performance is impaired. However, according to the processing efficiency theory, in response to the working memory detecting potentially harmful effects of anxiety on performance, the central executive can also evoke a motivational reaction to increase effort. Increased levels of effort mobilise auxiliary processing resources so that performance can be maintained, or even enhanced, as a result of greater on-task attention. As such, Eysenck and Calvo (1992) proposed two distinct types of performance related to the processing efficiency theory: effectiveness (i.e., the quality of performance) and efficiency (i.e., effectiveness divided by expended effort). Eysenck and Calvo (1992) contend that because performance can be maintained by compensatory increases in effort, anxiety has the potential to impair efficiency more than effectiveness.

Distraction theories have been empirically supported mainly by cognitive psychology research. Cognitive and declarative tasks which place extensive demands on the working memory, such as mathematical problems, are generally accepted to be detrimentally affected by pressure as a result of distraction (e.g., Beilock & Carr, 2005; Beilock *et al.*, 2004b). Similarly, distraction is implicated in the breakdown of sporting tasks which are heavily reliant on decision making for successful performance (see Williams *et al.,* 2002). In terms of motor performance, Smith *et al*., (2001) explored the relationship between anxiety, effort, and performance in volleyball players. Under different competitive pressure conditions, performance of low-trait anxiety players improved in response to increased effort, whilst performance of high-trait anxiety players deteriorated even though participants also reported exhibiting greater effort. Hardy and Hutchinson (2007) extended these findings to rock climbing, and found that broadly speaking, more difficult and more pressurised climbs evoked greater anxiety and effort. Performance was generally found to improve under pressure where effort increased in response to anxiety, but was impaired in the most anxious climbers. Wilson *et al*., (2007) aimed to provide a more objective view of the processing efficiency theory by employing HRV as a measure of effort, as the mid-frequency band (0.07-0.14 Hz) has been linked to effortful processing (see Mulder, 1992). However, although self-reported anxiety and effort increased in response to a high pressure golf putting task, HRV remained unchanged. The researchers highlighted that this null finding may be due to respiratory volume increasing as a somatic anxiety relaxation strategy, but this perspective remains unclear as respiration was not measured. Assuming there is merit to this limitation, the fact that performance accuracy remained unchanged under high pressure, suggests that processing efficiency theory may be supported by this set of results.

Closely linked to the theoretical stages of learning (e.g., Fitts & Posner, 1967) already discussed in this chapter, self-focus theories of choking alternatively suggest that an increase in inward attention is responsible for the breakdown of skill. Self-focus theories such as reinvestment (Baumeister, 1984) and conscious processing (Masters, 1992), propose that an increase in inward attention caused by anxiety, results in athletes exhibiting greater conscious monitoring and/or control of skill execution. According to learning theorists, expertise is generally characterised by automaticity, with skill execution processed outside working memory in the form of implicit procedural knowledge. When skilled athletes experience pressure, self-focus theories of choking indicate that self-consciousness can increase in an attempt to process skill in a more effortful manner. By reinvesting a well learned skill, athletes are susceptible to slower processing of task-relevant information and a greater number of performance errors, because execution is degraded to a level more akin with novice performance. In essence, increased self-focus under pressure can cause athletes to process performance more explicitly, and engage working memory in greater levels of conscious control (Masters & Maxwell, 2008). However, working memory is often unable to manage any additional demands, and therefore performance is detrimentally affected. Whilst this theory may explain choking in expert athletes, it is important to note that because novices naturally exhibit explicit control of skill, self-focus theories suggest that they are more likely to maintain performance under pressure (Masters, 1992).

As previously presented in this chapter, much literature exists to empirically support the harmful effects of internal focus on performance. Further evidence in favour of self-focus theories of choking has been offered by Beilock *et al*., (2002) in golf and football players. Firstly, elite golfers were able to maintain performance levels whilst completing a dual task, but a decline in putting performance was recorded when exposed to a self-focus condition. Secondly, experienced footballers were found to complete a dribbling exercise faster when exposed to a distraction condition compared to a self-focus condition. Although pressure was not included in these experiments, self-focus induced choking was proposed to have been supported, as dual task and distraction were considered to have prevented explicit monitoring, whilst self-focus was claimed to have encouraged a reduction in automaticity. Gray (2004) addressed this limitation by asking highly skilled baseball batters to perform under pressure in distraction and self-focus conditions. Not only did performance worsen in the self-focus condition, but it remained unchanged in the distraction task. Furthermore, kinematic data also suggested that erroneous sequencing and swing timing indicated explicit control of action, and was responsible for the breakdown of skill. Despite some methodological concerns regarding manipulation checks, potential overlap with distraction principles, and ecological validity (see Hill *et al*., 2010), the choking literature suggests that self-focus may prove the most plausible mechanism for performance detriments under pressure in expert athletes. However, both self-focus and distraction may play a role in performance under pressure when considering the type of skill being performed and the disposition of the athlete (Beilock *et al*., 2004c).

Preparatory Cardiac Activity

In a move towards utilising psychophysiological principles to provide greater objectivity in exploring the theories discussed above, cardiac activity in the seconds preceding skilled motor performance may offer valuable insights. A pattern of HR deceleration has been well established in sports such as golf putting (Boutcher & Zinsser, 1990), shooting (Tremayne & Barry, 2001), and darts (Radlo *et al*., 2002). Whilst historical studies (Lacey & Lacey, 1970, 1974, 1980) have proposed a relationship between preparatory bradycardia and attentional processes, further work to disentangle this relationship has been limited. The following narrative aims to provide an overview of associated theories and contemporary findings.

The Intake-Rejection Hypothesis

As alluded to above, a short-term phasic pattern of HR deceleration is well-documented in the seconds preceding skilled motor tasks. Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis provides a framework for explaining this phenomenon, by suggesting that pre-performance bradycardia may be indicative of external focus of attention. This hypothesis proposes that HR deceleration causes a reduction in blood pressure, which increases flow of environmental information to the brain by unloading the baroreceptors (Brunia, 1993). Conversely, an increase in HR prior to skill execution is believed to cause a promotion of the bulbar restraint upon the reticular formation, which can reduce the cortical response to external stimuli. Thus, in incidences of HR acceleration, this visceral afferent feedback model suggests environmental cues are not as impactful and so internal focus becomes the predominant attentional process (Hatfield *et al*., 1987).

This hypothesis is generally deemed to have been derived from early reaction time paradigm studies by Lacey and Lacey (1970), where a systematic HR deceleration was noted during a fixed foreperiod between ready and imperative signals. Outside of this research group, anticipatory HR between the 'Get Set' – 5 s delay – 'Go' command in participants who were about to climb a flight of stairs or perform a bicycle sprint, was found to initially accelerate until 1 s before the 'Get Set' command. HR deceleration was then predominantly observed between the 'Get Set' command and 1 s before the 'Go 'command (Stern, 1976). More recently, these principles have been explored in the context of sports requiring skilled motor performance (Cotterill & Collins, 2005; Neumann & Thomas, 2009; Radlo *et al*., 2002; Tremayne & Barry, 2001).

As previously indicated in this chapter, under the premise that experts are more likely to primarily engage in external and automatic processes, sports performance studies have generally looked to determine differences in cardiac activity between novice and expert populations in further exploration of this phenomenon. Whilst HR deceleration has been observed in participants of varying expertise, in reflection of learning theories (e.g., Fitts & Posner, 1967), preparatory bradycardia has been found to be more pronounced in groups with greater levels of skill acquisition (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009). For instance, Boutcher and Zinsser (1990) found that expert and novice golfers exhibited HR deceleration during the four heartbeats preceding 12-ft putts of 20 beats per min (bpm) and 15 bpm respectively. Neumann and Thomas (2009) similarly found that elite, experienced, and novice golfers, respectively exhibited HR deceleration of 12, 10, and 2 bpm during the 6 s preceding 8-ft putts, whilst Cooke *et al*., (2014) observed a deceleration of 20 bpm for experts, and 9 bpm for novices over the same time period and for the same length of putt. In contrast, a greater HR deceleration was observed by Konttinen *et al*., (1998) in less skilled shooters compared to highly skilled shooters. This result could somewhat undermine the otherwise persuasive evidence for HR deceleration being indicative of attentional processes, however, physical implications of postural stability may offer an explanation to the contradictory findings in this case. In line with attentional theories of skill acquisition, the greater magnitude of HR deceleration seen as a function of expertise in the seconds preceding skilled motor task execution, may accordingly indicate a greater engagement in preparatory external information processing (Neumann & Thomas, 2009). In golf putting for instance, these factors may include focusing attention on the anticipated path of the ball towards the hole, the hole itself, or the club.

Although these studies highlight differences between expert and novice preparatory cardiac activity, they have also demonstrated a number of similarities when exploring specific features of the cardiac pattern. For example, HR deceleration normally starts around 3-6 s before impact with the ball in golf putting studies. Experts begin HR deceleration around 6 s prior to ball impact, with the lowest HR recorded at the epoch closest to ball impact, whilst novices tend to begin decelerating later at around 3 s before striking a putt. Based on Lacey and Lacey’s (1974, 1980) interpretation of these HR changes, the earlier onset of HR deceleration in expert participants may be a result of more effective encoding of environmental information and/or greater focus on external cues (e.g., ball, aim line, and hole).

In accompaniment to these established bradycardic responses, HR acceleration has also been observed in the period before and after skilled motor performance. Golf putting studies have generally found HR to accelerate before preparatory deceleration begins. Similar to the bradycardia element of preparatory cardiac activity, the initial HR acceleration pattern seems to be more pronounced and starts earlier in experts than novices. According to the intake-rejection hypothesis, this initial HR acceleration phase suggests novice and expert performers consider how their body needs to move to execute a successful performance as part of pre-performance routines. Whilst this perspective makes sense for novices when considering established attentional processes associated with learning (e.g., Fitts & Posner, 1967), the fact that experts are generally thought to exhibit predominantly external focus in response to greater automaticity, may undermine the intake-rejection hypothesis. However, recent work has shown that elite athletes may be able to consciously modify movements during competition to maintain proficiency (Collins *et al.*, 2001; Nyberg, 2015). As such, initially greater levels of internal focus may be a feature of expert motor control planning and programming.

HR acceleration as an objective measure of internal focus of attention is further substantiated in studies which extend cardiac activity analysis to post-performance. For instance, Neumann and Thomas (2009) found HR to accelerate significantly (above baseline levels) after elite and experienced golfers performed a golf putt. However, novice performers did not exhibit the same post-performance acceleration pattern. In support of the intake-rejection hypothesis, this finding may reflect highly skilled individuals using their greater technical understanding in the time after hitting a putt to internally analyse and learn from previous performances, especially errors. Conversely, novice participants maintaining a decelerated HR for around 3 s after putting, could instead be indicative of gaining feedback from putt outcome – a naïve process which is less likely to influence technical changes. In combination, this body of work suggests that cardiac deceleration and acceleration in the seconds before and after skilled motor tasks may characterise attentional processes associated with preparation for action.

Most studies which have extended this research to further explore the relationship between preparatory bradycardia and attentional processes, have done so by asking participants to perform under different attentional instructions. For example, Radlo *et al*., (2002) found HR deceleration was more pronounced in novice dart throwing when participants were asked to focus their attention externally on the target compared to internally on their movements. However, although Neumann and Thomas (2011) found that attentional focus instructions had an effect on tonic HR, no phasic changes prior to participants executing a golf putt were observed. In sum, whilst the cardiac deceleration phenomenon has grown ever more established in skilled motor tasks, as previous work is limited, it is unclear how this pattern of cardiac activity may change as a function of attentional focus.

Physical Influences

As shown by Salazar *et al.*, (1990) though, not all studies have witnessed HR deceleration in the seconds preceding skilled motor performance. Salazar *et al*., (1990) attributed the null findings to the physical strain associated with holding a fully drawn bow weighing the equivalent of 14-22 kg. The addition of greater physical demands in this instance, may have evoked a cardiovascular response which ultimately overrode phasic bradycardia. This finding highlights the potential influence of physiological factors on preparatory cardiac activity, and that phasic HR changes could alternatively be a result of non-attentional factors. Although in agreement with Lacey and Lacey (1974) regarding the occurrence of HR deceleration in the contexts presented above, Obrist (1968) suggested that the underlying mechanism for the observed cardiac pattern was due to reduced muscle and metabolic activity. In terms of skilled motor performance, Obrist opposingly proposed that preparatory bradycardia is simply indicative of motor quieting, because sports requiring fine motor control largely consist of a period of stillness before skill execution (Cardiac-somatic coupling and uncoupling theory). In relation to golf putting for example, most performers will address the ball in a slightly bent over stance for a few seconds before initiating movement. In shooting and dart throwing, participants similarly exhibit a period of no movement before pulling the trigger or releasing the dart whilst finalising their aim. This behaviour is concurrent with the differences seen in HR deceleration as a function of expertise. The observation that HR deceleration starts sooner and is more pronounced in experts, could alternatively be because experts exhibit longer pre-performance routines than novices (Boutcher & Zinsser, 1990). As such, experts could be considered to adopt a final address position sooner than novices, and thus, motor quieting may occur earlier and to a greater extent than in novices. This perspective is further supported by the fact that novices have been shown to have less postural stability compared to experts (Andreeva *et al.*, 2020), and may therefore require additional muscle activity to maintain an optimal address position. However, studies in golf putting have contrastingly confirmed that muscle activity increases prior to movement initiation (Cooke *et al*., 2014), and that golfers generally exhibit rehearsal movements in seconds before skill execution as part of pre-performance routines (Cotterill *et al*., 2010). Therefore, Obrist's theory appears somewhat unfounded in a sporting context.

Given the sensitivity of the cardiovascular system however, other physiological reflexes must also be considered in review of preparatory cardiac activity. For instance, postural changes and associated cardiovascular responses have been extensively studied (Borst *et al*., 1982; Ewing *et al*., 1980). Whilst baroceptor stimulation is most synonymous with changing from a sitting to standing position and vice versa, it is not unreasonable to consider whether this may be influential in the HR deceleration phenomenon. For instance, bradycardia in preparation for golf putting could be reflective of the gravitational effects on HR associated with golfers bending over on addressing the ball. Again, the established expert novice differences in preparatory cardiac activity could be explained by disparities in pre-performance routine tendencies (Boutcher and Zinsser, 1990).

Similarly, the relationship between respiration and HR must be considered in this area of research. With HR deceleration naturally accompanying exhalation (respiratory sinus arrythmia), it remains difficult to completely rule out respiratory influences on this cardiac phenomenon. However, whilst Neumann and Thomas (2009) found 72% of elite participants exhaled prior to performing a golf putt, no dominant pattern of respiration was observed in experienced participants. As such, a relationship between respiratory patterns and pre-performance cardiac activity is unlikely.

Furthermore, with deceleration having been shown to last around 6 s in expert golfers, exhalation lasting this length of time is improbable, as respiration rate normally sits around 12-15 breaths/min for healthy adults (Folke *et al.*, 2003). In addition, Leher *et al*., (2003) concluded a 90 degree phase relationship between breathing and heart rate, meaning a delay in HR response to exhalation also needs to be accounted for. Alternatively, Helin *et al*., (1987) found that elite shooters pulled the trigger consistently later in the cardiac cycle compared to inexperienced shooters. This was proposed to occur either because elite shooters can identify the longer R-R wave interval associated with a lower HR, or because they shot during, or, at the end of exhalation. Although the evidence remains persuasive in terms of phasic bradycardia in the seconds preceding skilled motor performance being indicative of attentional processes, physical influences cannot be entirely discarded and should be considered when interpreting findings in this thesis.

Summary

In conclusion, attentional processes are strongly implicated in successful sports performance (Abernethy *et al*., 2007; Wulf, 2007), particularly when athletes are faced with pressurised scenarios (see Hill *et al.*, 2010). The constrained action hypothesis (Wulf *et al*., 2001a) and theories surrounding stages of learning (Fitts & Posner, 1967) encapsulate the benefits of external focus of attention. Psychophysiology may provide valuable insights in further understanding how to achieve and maintain optimal attention. The intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) proposedly describes an objective measure for attentional processes, with preparatory bradycardia in the seconds preceding skilled motor performance thought to be indicative of external focus. In line with external focus of attention being characteristic of expert performance (Fitts & Posner, 1967), observed differences in HR deceleration as a function of expertise (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009) support this hypothesis.

Pressure has been shown to affect performance (Gucciardi & Dimmock, 2008; Lewis & Linder, 1997; Oudejans, 2008; Williams *et al*., 2002; Wilson *et al*., 2006), physiological (Cooke *et al*., 2010; Stoker *et al*., 2017; Veldhuijzen van Zanten *et al.*, 2002) and kinematic measures (Cooke *et al.*, 2010, 2011; Pijpers *et al*., 2005; Nieuwenhuys *et al*., 2008), with the disruption of attentional processes (Baumeister, 1984; Eysenck & Calvo, 1992; Masters, 1992) implicated in the breakdown of skill in incidences known as choking (Beilock & Gray, 2007). Although recent work (Mesagno *et al*., 2011; Stoker *et al*., 2017, 2019) has begun to challenge Baumeister's (1984) longstanding assumption, previous research has generally employed methodological design based on all pressures having equivalent and additive effects. This thesis aims to use psychophysiological methods to expand this body of work and address previous limitations discussed below.

Limitations of Previous Research

As alluded to previously, in terms of performance under pressure, previous research has focused on applying pressure based on Baumeister's (1984) assumption that all pressures have equal and additive debilitative effects on perfromance. However, as revealed by the literature reviewed in this chapter, this position statement may warrant further consideration. Many studies exploring the psychophysiological effects of pressure may have interpreted theoretical implications similarly but employed different pressure scenarios. As such, further work is required to understand whether this perspective may have affected findings, and if pressures should be considered in isolation rather than equivalently.

The intake-rejection hypothesis may provide a promising objective measure of attention processes, however, bar a few exceptions (Neumann & Thomas, 2011; Radlo *et al.,* 2002), most contemporary work has focused on the first step of the traditional characterisation of optimal performance i.e., establishing expert novice differences. This has yielded important findings in terms of preparatory HR deceleration, but in comparison to other areas of research pertaining to attentional focus (e.g., the constrained action hypothesis), the intake-rejection hypothesis has received relatively little interest to aid progressive understanding. For example, more work is required to explore preparatory bradycardia in response to the manipulation of attention. Furthermore, specific analysis regarding the features of the HR deceleration profile (e.g., timing, magnitude, and rate of bradycardia) may provide insights as to how attention links to cardiac activity. To help account for physical influences and overcome ecological challenges, employing a more physically demanding skilled motor task may help to silence alternative physiological theories.

Aims of Thesis and Outline of Experimental Chapters

In consideration of the above literature, this thesis aimed to use psychophysiological methods to increase our understanding of preparation for action in relation to skilled motor tasks. More specifically, how phasic bradycardia in the seconds preceding performance may be indicative of attentional processes. Under the premise that pressure, task difficulty, and the introduction of a secondary task may influence attentional focus, this thesis intended to further explore the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) relative to performance. Moreover, this set of experiments planned to add to the growing literature which challenges the assumption that all pressures are equal (Baumeister, 1984).

Firstly, the experiment presented in chapter two sought to examine novice golf putting in response to isolated pressure manipulations. Psychological, physiological, performance, and kinematic data provided a strong multidisciplinary perspective when challenging Baumeister's (1984) extensively cited study claiming that all pressures, regardless of origin, evoke equal effects. Given the potentially debilitative implications of increased self-focus on performance as a result of heightened pressure (Baumeister, 1984; Masters, 1992), results were considered relative to performance and self-reported conscious processing.

Secondly, chapter three assessed how the well-established pattern of preparatory cardiac activity (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Cotterill & Collins, 2005; Neumann & Thomas, 2009, 2011) may change in response to task difficulty. Under the premise that increased task difficulty may affect attentional processes and that HR deceleration could be indicative of attentional focus, along with other psychophysiological variables, preparatory bradycardia was assessed in response to more difficult and easier putting scenarios amongst expert golfers.

The third empirical chapter used a combination of protocols form chapters two and three to extend findings in a large novice cohort performing a different skilled motor task – dart throwing. In addition to a series of conditions which manipulated task difficulty and pressure in isolation, the experiment presented in chapter four also introduced a dual task protocol to help further explore the relationship between attentional processes and pre-performance HR deceleration. Given that an increase in internal focus of attention has been linked to poor performance (Hardy *et al*., 1996; Lohse *et al*., 2010; Maddox *et al*., 1999; Wulf, 2013), the secondary task was expected to have a protective effect, as participants would be unable to exhibit disruptive attentional processes due to working memory being consumed. A new measure of attentional focus was also included in this study. The attention 'pie chart' extends previous measures, as not only does it indicate the extent of change in attentional focus, but it also helps to describe the direction of change i.e., if one type of attentional focus decreases, does another type of attentional focus become more prevalent.

Finally, chapter five aimed to expand the principles discussed in the previous three studies to a more physically demanding skilled motor task, a full golf swing. The main opposing theory to the intake-rejection hypothesis suggests that the HR deceleration phenomenon is indicative of muscle and metabolic quieting (Obrist, 1968). With more physically demanding tasks generally requiring a greater cardiovascular response, the confirmation of preparatory bradycardia in the seconds before a full golf swing was proposed to help further substantiate the intake-rejection hypothesis.

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CHAPTER TWO

The Psychophysiological and Kinematic Effects of Isolated Pressure on Novice Performance; Are All Pressures Equal?

Abstract

Baumeister's (1984) classic paper on choking under pressure has been cited over 2000 times, yet there is limited empirical evidence to support his argument that pressures are equally debilitative. The present study aimed to evaluate performance in relation to different types of isolated pressure, and establish whether psychological, physiological or kinematic measures were affected equally as a result. 81 participants performed a series of putts under control and eight counterbalanced pressure conditions. The isolated pressure conditions proved to significantly alter both performance and mental state. Participants reported feeling under more pressure in all conditions when compared to control except the distraction task. Similarly, conscious processing and effort increased in all conditions in comparison to control apart from the distraction and time constraint scenarios. Performance on the other hand only decreased in the video, time constraint and increased difficulty conditions. Meanwhile heart rate increased in four out of the eight pressure conditions, and various kinematic differences were observed in lateral, vertical and longitudinal planes across conditions. These results indicate that different types of pressure can affect performance in different ways. Furthermore, the mechanistic properties of performers choking or exceling under pressure, may be a dependant on the type of pressure/s. Further research exploring these theoretical implications, is required to help better inform performance under pressure methodology, and improve the psychophysiological understanding of choking models.

Introduction

The ability to perform well in pressurised scenarios continues to attract much attention from the academic community. Pressure can stem from *'any factor or combination of factors that increases the importance of performing well on a particular occasion'* (Baumeister, 1984), and can occur in a variety of sectors, (e.g., business, military, emergency medicine) but in sport, regardless of the underlying rationale, there is strong agreement that the desire to succeed can elicit pressure to perform (Beilock & Carr, 2001). However, recent research (Mesgano *et al*., 2011; Stoker *et al*., 2017, 2019) exploring the effects of isolated pressure manipulations, suggests that Baumeister's (1984) extensively cited assumption that all pressure creates equal and/or additive effects on performance, perhaps warrants closer scrutiny.

Regardless of where the pressure to perform originates, empirical (e.g., Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992) and anecdotal (e.g., Rory McIroy in 2011 U.S. Masters golf tournament, the England Senior Men's Football Team in major tournament penalty shoot-outs) evidence suggests that athletes sometimes underperform when the stakes are high. The process of not being able to maintain performance in the face of pressure is called choking (Beilock & Gray, 2007). The three primary mechanistic theories (Distraction, DeCaro *et al*., 2011; Reinvestment, Baumeister, 1984; Processing Efficiency, Eysenck & Calvo, 1992) for choking under pressure revolve around attentional processes. Conscious processing (Masters & Maxwell, 2008) and effort (Eysenck & Calvo, 1992) are self-report measures which have been closely linked to these processes and are synonymous with pressure research. In golf putting, effort has been shown to have a positively linear relationship with pressure (Cooke *et al*., 2010), whilst increased trait conscious processing tendencies has been implicated in the kinematic disruption of golf putting known as the 'yips' under pressure (Klämpfl *et al*., 2013).

Irrespective of the mechanistic properties of choking under pressure, the effects are perhaps most synonymous with elite sport, where the demands and consequences of performing are greatest. However, under Baumeister and Showers (1986) broad and situational definition of performance (i.e., an individual can be termed as ‘performing’ whenever they carry out a task in a situation which requires an optimal outcome), all skill levels are susceptible to choking. It is widely accepted therefore, that increased pressure can detrimentally affect performance (Hill *et al*., 2010). More specifically, Williams *et al*., (2002) found that table tennis performance was impaired by pressure in response to evaluation and competition, whilst Wilson *et al.,* (2006) reported that ego-threatening instructions and the opportunity to win £50 negatively impacted driving performance. Moreover, Oudejans (2008) showed that police officer’s handgun shooting performance significantly worsened when faced with an opponent which fired back (high pressure), compared to shooting at a carboard cut-out (low-pressure). In combination, these studies demonstrate that a variety of methods can be used to explore the ramifications of impaired performance as a result of increased pressure.

In a research context, pressure can be induced by manipulating the task, the performer, and/or the environment. More specifically, the task may be manipulated by altering target size, distance from target, and randomised versus block task completion to modify task difficulty (Stoker *et al*., 2017, 2019). Meanwhile, introducing physical and/or psychological factors which have the potential to affect normal function, have been shown to induce pressure through fatigue e.g., Stroop Test (Provost & Woodward, 1991). Alternatively, environmental manipulations were employed by Oudejans and Pijpers (2009) where pressure was induced by increasing the height where participants performed a dart throwing task from, whilst Driskell *et al*., (2001) used sound to induce pressure through noise distraction. Similarly, the introduction of consequences (positive or negative) has been shown to increase perceived pressure. As part of wider interventions, rewards, punishment, and evaluation have all been used to increase pressure (e.g., Bell *et al*., 2013; Driskell *et al*., 2014; Oudejans & Pijpers, 2009, 2010; Stoker *et al*., 2017, 2019). Specific examples of increasing pressure through the introduction of a negatively perceived consequence, include the threat of cleaning a changing room (Bell *et al*., 2013) or participating in a staged media conference (Stoker *et al*., 2019). Furthermore, Driskell *et al*., (2014) found that pressure increased in response to peer and/or coach evaluation, whilst Mesagno *et al*., (2011) reported increased pressure regardless of whether the evaluation was in person (i.e., audience) or remote (i.e., video recording to be assessed later by a figure of importance). Research which has used rewards-based consequences to manipulate pressure, commonly feature performance-contingent monetary incentives (Belilock & Carr, 2001; Masters, 1992, Oudejans & Pijpers, 2009). In addition, competition has been shown to induce pressure (Baumeister & Showers, 1986), with individual sports generally considered to evoke greater pressure than team sports (Martin & Hall, 1997). However, ego-threat may have the potential to induce choking when performers are faced with an individualistic scenario that could directly affect teammates (Baumeister, 1997).

Although these different manipulations arguably represent distinct nuances of pressure research, ease of application and ecological relevance are often key considerations in methodological design. Researchers understandably further rationalise the selection of specific manipulations by addressing the suitability of a manipulation to explore specific hypotheses (e.g., Mesagno *et al*., 2011 selected video recording for its ability to heighten self-consciousness whilst exploring self-presentation and choking,), and use existing literature to strengthen validation (e.g. Wilson *et al*., 2006 selected ego-threat as the high-pressure condition because previous studies had found it to be a successful way of inducing pressure before task completion). Moreover, to ensure an increase in pressure is achieved, manipulations are often used in combination (Cooke *et al*., 2010, 2011, 2014) and as part of a wider experimental protocol (Bell *et al*., 2013). These inconsistencies mean a fundamental lack of clarity remains as to whether isolated pressure manipulations cause equivalent effects.

Recent literature has begun to challenge this assumption by exploring how different isolated pressures affect performance. Mesagno *et al*., (2011) used varying manipulations of evaluation and monetary rewards to induce pressure in a field hockey task. Contrastingly, performance was found to decline in groups that were exposed to themes of self-presentation, but improvements were recorded in the performance-contingent monetary incentive and video-camera placebo groups. Meanwhile, Stoker *et al*., (2017) observed that isolated pressure conditions involving consequences (e.g., evaluation, reward, and forfeit), resulted in significantly higher levels of pressure compared to a control condition, but performance only decreased in response to the presence of a task or environmental manipulation (e.g., occlusion goggles, time constraint, and noise distraction). Conversely, although Stoker *et al*., (2019) confirmed that consequences were crucial for inducing pressure in a follow up study, the forfeit condition actually corresponded to a performance improvement when compared to the condition where participant's psychological ability was manipulated (cognitive pre-fatigue induced by Stoop test). In combination, these preliminary studies begin to support the notion that different isolated pressures do not produce equal effects on performance.

Above and beyond performance and self-report data, there is a growing trend towards obtaining a greater understanding of how pressure affects physiological and kinematic measures. For example, it is generally assumed that heart rate (HR) can provide an objective indication of anxiety (Åstrand *et al*., 2003). High-pressure situations can evoke anxiety (Staal, 2004) and therefore, in studies involving skilled motor tasks, an elevation in HR can be considered as a measure of pressure (Cooke *et al*., 2010; Oudejans & Pijpers 2009, 2010; Stoker *et al*., 2019). In terms of isolated pressure manipulations, studies have found HR to increase in competition (Veldhuijzen van Zanten *et al.*, 2002) and in response to increased task difficulty (Carroll *et al.*, 1986). In elite netballers, isolated consequence-based pressures and combined consequence and task manipulation pressures, were found to induce a higher HR compared to control, whilst isolated conditions where the task was manipulated were found to have no effect on HR (Stoker *et al*., 2017). Similarly, heart rate variability (HRV) has been increasingly used as a measure of anxiety and greater effort. Often assessed in low (0.02-0.06 Hz), mid (0.07-0.14 Hz), and high (0.15-0.50 Hz) frequency bands (Mulder, 1992), changes are influenced by the sympathetic and/or parasympathetic systems; both of which are implicated in the body's psychophysiological reflex to pressure. Cooke *et al*., (2010) showed that SDNN (the standard deviation between R-wave intervals), a correlate of the mid-frequency band (Carrasco *et al*., 2001) which has been linked to mental effort (Mulder, 1992), increased with high pressure. Although Wilson *et al*., (2007) conversely found no change in mid-frequency band HRV under pressure, cardiovascular measures may provide an objective indication of performance under pressure, as HRV can also be influenced by an increased respiratory volume resulting from somatic anxiety relaxation strategies.

Muscle tension is another measure which has been found to increase with anxiety (e.g., Duffy, 1932), and thus, can be used as a psychophysiological measure to explore the effects of pressure. In a tennis ball throwing task for example (Weinberg & Hunt, 1976), electromyography (EMG) revealed that participants who experienced high levels of anxiety contracted their biceps and triceps (agonist and antagonist muscles respectively) for longer in response to pressure compared to the low anxiety group. Moreover, where participants were not affected by increased muscle tension (i.e., low anxiety group), performance was shown to improve under pressure. Likewise, Cooke *et al*., (2010) found that increased EMG activity in muscles associated with putting stroke biomechanics, accompanied a decreased number of holed putts when participants were subjected to a high-pressure condition. These findings indicate that neuromuscular inefficiency in response to pressure may be influential on performance outcome.

Previous research also suggests that pressure can elicit effects on movement kinematics (Cooke *et al.*, 2010, 2011; Pijpers *et al*., 2005; Nieuwenhuys *et al*., 2008). For instance, climbers have been found to make longer-lasting reaching movements and take longer to transverse a wall in response to increased pressure (Pijpers *et al*., 2005; Nieuwenhuys *et al*., 2008). Similarly, Maxwell *et al.*, (2003) found participants had less accurate putting strokes under pressure, with one dimensional (back and forth movement) swing mechanics analysis revealing increased jerkiness and decreased smoothness. Mullen and Hardy (2000) on the other hand, noted no effects of pressure on putting stroke kinematics following two-dimensional analysis (both club and arm movement). More recently, Cooke *et al.*, (2010) suggested that novice participants missed putts under pressure because of increased lateral clubhead acceleration. Together, these studies suggest that movement kinematics can be disrupted by pressure and may impact performance as a result.

In combination, these studies suggest that pressure may have varying effects on psychophysiological and kinematic measures in skilled motor tasks. Although an abundance of literature exploring performance under pressure exists (Baumeister, 1984; Beliock & Carr, 2011; Cooke *et al*., 2010, 2011; DeCaro *et al*., 2011, Wilson *et al*., 2007), there is little evidence to support our understanding of how isolated pressures effect performance. Furthermore, although researchers have recently begun to favour multi-disciplinary studies, little is known about the psychophysiological and kinematic effects of isolated pressures, and only a handful of studies have assessed these parameters simultaneously. Such research could help further validate laboratory or field-based pressure studies, whilst providing additional insight into the mechanistic properties of performing under pressure.

In exploration of Baumeister's (1984) perspective on pressure evoking equal effects, this study sought to determine whether contrasting isolated pressure manipulations produce equal psychological, performance, physiological, and kinematic effects on novice golfers. Based on the previous research outlined above, this study aimed to induce pressure by exposing participants to isolated manipulations such as, increased task difficulty, competition, consequences (reward, punishment, and evaluation), and environmental distractions. Perceived pressure and self-reported effort were expected to increase in all conditions compared to control. Meanwhile, conscious processing was expected to increase in all conditions except the time constraint, where a decrease was anticipated. Performance was hypothesised to be detrimentally affected by consequence-based conditions and conditions where task difficulty increased. Physiological measures of HR and muscle tension were predicted to increase with pressure. Pressure was also expected to cause a decrease in HRV and disrupt movement kinematics towards a less accurate swing pattern.

Method

Participants

Male (*n* = 20) and female (*n* = 61) right-handed sport and exercise sciences students participated in exchange for course credit. All participants (*M* age = 20.0 years, *SD* = 1.1 years) were novices, with no previous golf training (i.e., no formal handicap). Informed consent was obtained prior to participation.

Performance Measures

Number of holed putts was the performance outcome measure, whilst mean radial error (i.e., the average distance the ball finished from the hole) acted as a measure of performance accuracy (0 cm indicated a holed putt). Mean radial error was recorded as the distance from the centre of the hole to the closest point of the ball. As an increase in time taken to perform a task has also been associated with performance under pressure (Nieuwenhuys *et al*., 2008), time taken to complete each block of 9 putts was also recorded (i.e., seconds between hitting the first and last putt).

Psychological Measures

Conscious processing. Conscious processing while putting has been implicated in self-focus theories of choking under pressure (Baumeister, 1984), and in some previous work, reinvestment processes have been associated with kinematic disruption (Klämpfl *et al.*, 2013). As such, conscious processing was measured using the 6-item putting-specific conscious motor processing scale (Cooke *et al*., 2011) to confirm reinvestment tendencies under pressure. Participants were asked to indicate how they felt about the previous 5 putts (e.g., "*I thought about my putting stroke*", "*I tried to figure out why I missed putts*") on a 5-point Likert scale, anchored by 1 ("*never*") and 5 ("*always*"). In line with past research (Cooke *et al.,* 2011) the internal consistency of the scale was very good (α = .81 to .92) across conditions.

Pressure and effort. Pressure and effort were measured using the 5-item pressure/tension and effort/interest subscales of the Intrinsic Motivation Inventory (Ryan, 1982). Self-reported pressure was employed as the manipulation check, whilst effort was primarily measured to confirm task engagement and facilitate insights regarding the relationship between HRV and effort. However, self-report effort data also allowed further exploration of how changes in this construct may contribute to the choking paradigm, i.e., processing efficiency theory (Eysenck & Calvo, 1992). Participants were instructed to rate each item (e.g., "*I felt pressured*", "*I tried very hard to do well*") on a 7-point Likert scale anchored by 1 "*not at all*" and 7 ("*very true*"). The internal consistency of the pressure (α = .89 to .94) and effort (α = .92 to .95) subscales were very good across conditions.

Physiological Measures

Cardiac. An electrocardiogram was recorded using three silver/silver chloride spot electrodes (Cleartrace, ConMed, Utica, NY) in a modified chest configuration. The signal was amplified (Delysys® Bagnoli-4 EMG system, Boston, MA), filtered (1-100 Hz), and digitalized at 2500Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK) using Spike2 software (Cambridge Electronic Designs). For each condition, tonic HR (Heart Rate) and two-time domain indices of HRV (SDNN; standard deviation of R-wave to R-wave intervals, r-MSSD; root mean square of successive R-R intervals) were calculated from the electrocardiographic recordings. An interactive program was used to score analog electrocardiographic signals. Although R-wave peaks were automatically identified, visual inspection and manual movement of scored points ensured correct identification.

Muscle Activity. EMG of the left flexor carpi radialis and left biceps brachii muscles were measured continuously. Previous studies (Smith *et al*., 2000; Stinear *et al*., 2006) have implicated these muscles as the main disrupters of putting biomechanics. Muscle activity was recorded via single differential surface electrodes (DE 2.1, Delsys®, Boston, MA) and an amplifier (Delysys® Bagnoli-4 EMG system, Boston, MA) with a ground electrode attached on the collar bone. EMG signals were amplified (Power 1401, Cambridge Electronic Design, Cambridge, UK), filtered (20-450 Hz), digitalized (2500 Hz), and recorded using Spike 2 software. The mean amplitude (millivolts) for each muscle during each condition was calculated by averaging total activity over the five putts. To analyse changes in muscle activity throughout the putting stroke, EMG was also calculated for four consecutive periods: pre-initiation, upswing, downswing, and post-impact. These periods were time-locked using the Z-axis acceleration profile (described below). The end of the pre-initiation period was the same duration as the upswing movement and signalled the start of this phase. The downswing period began once the upswing epoch had reached its pinnacle and lasted from this point until ball impact. The post-impact portion of the stroke was the same duration as the downswing and begun immediately after impact with the ball.

Kinematic Measures

Movement Kinematics. A tri-axial accelerometer (ADXL337 Breakout, Cool Components, UK) was used to record clubhead acceleration in three planes. Lateral, vertical, and back-and-forth movements were calculated via X, Y, and Z acceleration axes respectively. An impact sensor (Piezo Vibration Sensor, Measurement Specialties Inc, USA) was used to detect when contact between the putter and ball occurred. The impact sensor and accelerometer were both recessed into the underside of the putter clubhead. Movement kinematics for each putt was assessed from the onset of the downswing phase to the point of impact with the ball. The average X, Y, and Z acceleration was calculated. The Z axis was also used to calculate root mean square jerk and smoothness for each putt, as it is regarded as the primary axis involved in putting (see Maxwell *et al.*, 2003). Mean kinematic variables for each condition was established by averaging the values over all five putts.

Conditions

In addition to a no pressure control condition, previous findings (Baumeister & Showers, 1986; Stoker *et al*., 2017, 2019; Mesgano *et al*., 2011) informed the design of eight isolated pressure conditions. Experimental conditions aimed to embody psychological constructs associated with increased pressure, such as the introduction of a consequence (competition, reward, punishment, and evaluation), an environmental distraction, or manipulating task difficulty. In contrast to Baumeister's (1984) model of equal pressures, these conditions were used to test the hypothesis that isolated pressures do not elicit equal effects.

Control. Standard golf equipment is designed to help players achieve success, i.e., increase the likelihood of holing a putt above and beyond the user's ability by designing features such as face angle and clubhead shape to help optimise stroke biomechanics and impact accuracy. Inevitably, novice performers may therefore hole a greater number of putts using commercial equipment than is representative of their ability. To overcome this potential bias, a bespoke putter was manufactured. The putter consisted of an 81 cm long completely upright shaft, centred in a semi-circular aluminium club head (height = 2.5 cm; face width = 7.5 cm; radius = 3.5 cm), with putts struck using the flat face unless otherwise stated. Participants putted five standard sized golf balls (Ultra, Wilson) 2 m to a target hole, located centrally 1.25 m from the end of a 1.5 m x 5 m indoor artificial putting surface (Augin Turftiles), prior to and after the eight pressure conditions. The surface measured 4.27 m using a Stimpmeter, which is faster than most greens, as according to the US Golf Association, readings will generally range from 2.13 m to 3.66 m on competitive courses. The hole was also modified (depth = 1.5 cm; width = 7 cm) to form a shallow, straight sided aperture. The depth of a standard golf hole often means that despite a ball travelling at a speed which would result in it finishing past the hole, some putts are successfully holed. Furthermore, the circular lip of a traditional golf hole means that in instances where a ball is travelling along the edge of the hole, if it does not 'drop-in' or run past the hole, it may 'lip' around the back of the hole and come to rest on the opposite side of the hole. Like commercially available putters, this phenomenon has the potential to distort performance statistics. Hence, to minimise interference with performance data, the hole used in this study was designed to have straight edges in line with direction travel of the ball, and only a putt travelling at a speed of 10-15 cm past the hole (the pace recommended by most professional golfers) was likely to be holed.

Increased difficulty. Participants were instructed to putt using the rounded side of the semi-circular headed putter (i.e., reverse side). The rounded face was designed to test accuracy, with inaccurate swing planes and inconsistent strike patterns exaggerating any off-centre miss-hit. Stoker *et al.*, (2016) noted that coaches increase task difficulty to generate pressure during training, whilst laboratory-based studies have confirmed that manipulating difficulty can influence anxiety, performance (Oudejans & Pijpers, 2009, 2010), and HR (Carroll *et al.*, 1986).

Video. Participants were filmed by the experimenter holding a video camera with lighting attachment. They were told that the footage would be used during an upcoming golf professionals conference, implying that their putting performance would be viewed and evaluated by a large audience of experts (Geukes, 2012). Videotaping was expected to increase self-evaluation (Buss, 1980), self-consciousness (Lewis & Linder, 1997), and self-presentation concerns (Mesagno *et al.*, 2011). To reduce the likelihood of participants becoming acclimatised to videotaping, and thus, potential pressure effects declining, the experimenter changed position of filming every second putt, gradually becoming more obtrusive and increasingly present in the participant's line of sight.

Time Constraint. Participants were given 15 s to putt all five balls. A countdown timer was placed in the participants line of sight, which visually and audibly signified time elapsing. As suggested by skill acquisition literature (Beilock *et al.*, 2004), declarative stage novice performers require the opportunity for conscious monitoring and control, therefore by reducing the time available to plan and process movement, performance may be detrimentally affected.

Team. Participants were told that they had been randomly paired with another participant to form a team. Using number of holed putts from the pre-test control condition, an achievable target to beat was calculated to give the impression that the competition against another team was close. When faced with a scenario that will directly affect other team members, it is thought that pressure stemming from ego-threat may cause athletes to perform poorly (Baumeister, 1997).

Target to beat. Participants were given a target to beat based on their pre-test control performance. Baumeister's (1984) analysis of pressure, suggests that pressure is possible when performers want to do well. Thus, participants can be susceptible to choking when trying to do their best.

Fame. Participants were presented with a leader board entitled the "*wall of fame*", containing names and photos of what the participant believed were the best performers (details were randomised and unrelated to the study). Moreover, participants were awarded £1 for every putt holed (stacked in line of sight). Monetary rewards and social evaluation are strong themes in pressure research (e.g., Beilock & Carr, 2001; Cooke *et al*., 2011; Wilson *et al*., 2007).

Shame. A "*wall of shame*" was fabricated to create the illusion of a worst performance leader board. Furthermore, participants were informed that they had been granted £5 for volunteering for the study; however, for every putt they missed during this condition, they would lose £1. The £5 stack of coins was placed in the participants direct sight, with a £1 coin removed following every missed putt. The potential for losing money as a consequence of poor performance has previously been shown to increase pressure (Cooke *et al*., 2011).

Distraction. Whilst participants performed under control instructions, increasingly audible noises were progressively introduced (running tap, chatter, and metal bin lid slam). Previous findings indicate that pressure can stem from the performance environment, and distractions such as noise, can detrimentally affect skilled motor performance (Driskell *et al*., 2001; Stoker *et al*., 2017, 2019).

Procedure

The protocol was approved by the local research ethics committee. Electrocardiogram and EMG skin sites were exfoliated and cleaned before all electrodes were attached using specialist electrode interfaces and secured with medical tape. Participants completed five practice putts to familiarise themselves with the putting surface and equipment. Using a within-participant design, participants completed the "*pre-test*" control, eight pressure conditions counterbalanced using a Latin square design (Williams, 1949), and a "*post-test*" control condition. To help account for any learning effects, the data of "*pre*" and "*post*" control conditions were averaged so that the control condition best represented each participant's typical putting-related thoughts, feelings, and actions. No instructions or suggestions were given prior to or during the experiment regarding putting technique. Participants were informed repeatedly throughout the experiment to complete putts at their own pace and reminded that performance would be assessed in terms of number of holed putts and mean radial error; therefore, they should not only aim to get the ball in the hole, but to finish it as close to hole as possible. A £20 reward was offered for the best overall performer to encourage a consistent level of task engagement. Each pressure condition was explained and administered by the experimenter using a script, and prior to each putt the ball was placed in the designated spot by the experimenter to avoid any electrocardiogram or EMG artefacts as a result of postural changes from the participant. Physiological and kinematic measures were recorded continuously during each condition. Immediately after participants had finished the five putts in each condition, they completed self-report questionnaires for pressure, effort, and conscious processing using a tablet computer. As such, this procedure allowed participants approximately 3 min rest between each condition.

Statistical Analysis

A series of 9 pressure condition repeated measures analysis of variance (ANOVAs) on psychological, performance, physiological, and kinematic variables yielded effects for all variables (Table 2.1, right hand column), except r-MSSD, $F(8,73) = 1.17$, $p = .33$ $\eta^2 = .11$, and left biceps brachii muscle activity, $F(8,73) = 1.13$, $p = .36$ $\eta^2 = .11$. Subsequent 2 condition (pressure and control) pairwise comparison analysis (least significant difference) informed by the repeated measures ANOVAs, were used to investigate the effects of each isolated pressure condition compared to control (Table 2.1, superscript text). Significant differences were deemed to exist if comparative values were outside the 95% confidence interval.

A series of 9 condition × 4 phase (pre-initiation, upswing, downswing, post-impact) repeated measures ANOVAs determined a main effect on muscle activity for condition, $F(8,73) = 3.43$, $p < .005$, $\eta^2 = .27$ and phase, $F(3,78) = 35.32$, $p < .001$, $\eta^2 = .58$ (Figure 2.1). Subsequent separate 9 condition x 4 phase repeated measures ANOVAs were employed to compare muscle activity between phases for each muscle site.

By using the multivariate method for reporting results, the risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVAs was minimised (Vasey & Thayer, 1987). Partial eta squared (η^2) indicates effect size, with small, medium and large effects sizes corresponding to values of .02, .13, and .26 respectively (Cohen, 1992).

Results

Effects of Pressure on Psychological Measures

The separate 9 condition repeated measures ANOVAs found main effects for pressure condition on the self-report measures: perceived pressure, effort, and conscious processing (Table 2.1, top). Subsequent pairwise comparison analysis confirmed that perceived pressure and effort were greater in seven out of the eight pressure conditions relative to control. The distraction condition was the only manipulation where perceived pressure and effort did not increase compared to control. Conscious processing increased in most conditions, except in the distraction condition where there was no difference compared to the control condition. In contrast, conscious processing was lower in the time constraint condition than the control condition.

Effects of Pressure on Performance

The 9 condition repeated measures ANOVAs confirmed main effects for pressure condition on putts holed, mean radial error, and time (Table 2.1, middle). Pairwise comparison analysis revealed that pressure impaired the number of holed putts in the increased difficulty, time constraint, and video conditions compared to control. In terms of mean radial error, pressure reduced performance accuracy in the increased difficulty and time constraint conditions. In contrast, putting was more accurate in the team, target to beat, and shame conditions compared to control. Finally, participants completed their nine putts faster in the time constraint and increased difficulty conditions, whereas they were slower in the other pressure conditions compared to control.

Effect of Pressure on Physiological Measures

The 9 condition repeated measures ANOVAs indicated main effects of pressure condition for HR and SDNN but not r-MSSD (see Table 2.1 middle). Pairwise comparison confirmed that HR increased relative to control in the time constraint, team, fame, and shame conditions. Compared to control, SDNN increased in the target to beat condition, but decreased during the time constraint condition.

In terms of muscle activity, the 9 condition repeated measures ANOVAs yielded a condition main effect for left flexor carpi radialis EMG, but not for left biceps brachii EMG (see Table 2.1 middle). Follow up pairwise comparisons indicated that only the time constraint condition produced an increase in left flexor carpi radialis EMG, compared to control; suggesting participants gripped the club tighter when putting under a time constraint. The separate 9 condition x 4 phase repeated measures ANOVAs (Figure 2.1) conducted for each muscle revealed condition, $F(8,73) = 3.24$, $p < .01$, $\eta^2 = .26$, phase, $F(3,78) = 26.77$, $p < .001$, $\eta^2 = .51$ and phase x condition, $F(24,57) = 4.77$, $p < .001$, $\eta^2 = .67$, effects for left flexor carpi radialis EMG. In general, these results reflected left flexor carpi radialis activity increasing from the pre-initiation to upswing phases of the putting stroke, $F(1,80) = 14.72$, $p < .001$, $\eta^2 = .16$, and between the upswing and downswing phases, $F(1,80) = 75.47$, $p < .001$, $\eta^2 = .49$. Muscle tension then remained high between the downswing and post-impact phases of the swing, $F(1,80) = 1.47$, $p = .23$, $\eta^2 = .02$. Similarly, condition, $F(8,73) = 2.39$, $p < .05$, $\eta^2 = .21$, phase, $F(3,78) = 23.83$, $p < .001$, $\eta^2 = .48$, and phase x interaction, $F(24,57) = 1.92$, $p < .05$, $\eta^2 = .45$, effects for left biceps brachii were confirmed. Between the pre-initiation and upswing phases muscle activity increased, $F(1,80) = 6.63$, $p < .05$, $\eta^2 = .08$, and then again from upswing to downswing, $F(1,80) = 44.50$, $p < .001$, $\eta^2 = .36$. As with the left flexor carpi radialis, muscle tension remained high in the left biceps brachii between the downswing and post-impact phases of the swing, $F(1,80) = 2.19$, $p = .14$, $\eta^2 = .03$.

Effect of Pressure on Kinematic Measures

Separate 9 condition repeated measures ANOVAs yielded effects for pressure condition on all kinematic measures (Table 2.1, bottom). Subsequent pairwise comparison analysis of X-axis acceleration revealed that participants exhibited less lateral movement during the increased difficulty, video, team, target to beat, and shame conditions compared to control. Y-axis acceleration analysis showed that participants swung the club head closer to the putting surface in the increased difficulty, team, fame, and shame conditions, compared to control. In contrast, participants generally swung the club further away from the putting surface during the time constraint condition, compared to control. In terms of Z-axis acceleration, participants swung the putter significantly slower in the increased difficulty and video conditions compared to control. In line with the demands of the task, Z-axis acceleration was conversely found to increase during the time constraint condition in comparison to control.

The 9 condition repeated measures ANOVAs also yielded main effects for pressure condition on the Z-axis derivates: RMS jerk and smoothness (Table 2.1 bottom). Subsequent pairwise comparisons showed that RMS jerk decreased in the increased difficulty, video, and shame conditions compared to control. However, RMS jerk increased when participants were exposed to a time constraint compared to control. Smoothness decreased in the increased difficulty, time constraint, target to beat, and fame conditions, compared to control.

	Pressure Condition										
	Control	Increased Difficulty	Video	Time Constraint	Team	Target to Beat	Fame	Shame	Distraction	*F(8,73)*	η^2
Measure (range of scores possible)	Mean (*SD*)										
Psychological											
Perceived Pressure (1-7)	2.55 (1.07)	2.81[a] (1.21)	3.17[a] (1.37)	3.68[a] (1.50)	3.25[a] (1.33)	2.99[a] (1.23)	3.44[a] (1.36)	3.68[a] (1.44)	2.59 (1.22)	15.83***	.63
Effort (1-7)	4.59 (1.24)	4.87[a] (1.37)	4.89[a] (1.37)	4.88[a] (1.42)	5.41[a] (1.30)	5.16[a] (1.28)	5.41[a] (1.24)	5.36[a] (1.37)	4.73 (1.32)	14.42***	.61
Conscious Processing (1-6)	3.37 (0.65)	3.66[a] (0.76)	3.63[a] (0.75)	2.77[a] (0.83)	3.71[a] (0.70)	3.65[a] (0.77)	3.71[a] (0.76)	3.64[a] (0.78)	3.47 (0.75)	15.26***	.63
Performance											
Mean Radial Error (cm)	34.13 (15.67)	42.14[a] (17.87)	33.38 (18.11)	45.97[a] (28.35)	27.90[a] (15.02)	28.94[a] (12.65)	30.14 (15.56)	29.37[a] (14.28)	31.56 (19.19)	8.60***	.49
Number of Holed Putts (0-5)	0.79 (0.66)	0.30[a] (0.49)	0.53[a] (0.69)	0.44[a] (0.72)	0.91 (0.85)	0.75 (0.99)	0.64 (0.93)	0.63 (0.91)	0.72 (0.91)	5.55***	.38
Overall Time (s)	23.36 (3.74)	22.39[a] (4.21)	24.64[a] (6.45)	11.29[a] (2.83)	24.60[a] (5.65)	24.21[a] (4.64)	25.14[a] (5.06)	26.94[a] (7.14)	26.04[a] (5.77)	86.03***	.90
Physiological											
Heart Rate (bpm)	83.59 (10.47)	82.82 (11.65)	84.01 (12.50)	85.72[a] (10.97)	85.34[a] (10.50)	83.77 (11.15)	86.48[a] (11.92)	87.00[a] (12.72)	82.54 (11.25)	5.73***	.39
SDNN (ms)	59.24 (1.76)	61.36 (2.99)	60.64 (2.95)	46.51[a] (2.72)	65.73 (3.44)	68.17[a] (3.57)	58.48 (2.43)	64.27 (2.71)	61.57 (2.56)	4.39***	.33
r-MSSD (ms)	39.90 (22.23)	44.22 (43.82)	42.93 (34.16)	35.99 (29.29)	43.64 (36.46)	46.16 (40.81)	38.45 (29.16)	42.26 (32.67)	40.07 (25.38)	1.17	.11
Left Extensor Carpi Radialas EMG (μV)	9.05 (4.28)	9.36 (4.55)	9.30 (5.35)	11.37[a] (5.78)	8.75 (4.21)	8.76 (4.09)	8.84 (3.95)	8.92 (4.32)	10.21 (14.58)	6.66***	.42
Left Biceps Brachii EMG (μV)	22.36 (21.92)	33.17 (52.21)	28.39 (46.68)	23.29 (30.76)	18.93 (26.53)	25.05 (38.95)	24.15 (29.51)	22.86 (30.94)	25.33 (35.93)	1.13	.11
Kinematic											
X-axis acceleration ($m.s^{-2}$)	2.26 (0.52)	1.10[a] (0.24)	2.10[a] (0.56)	2.31 (0.66)	2.10[a] 0.54)	2.14[a] (0.52)	2.18 (0.56)	2.09[a] (0.49)	2.16 (0.56)	140.33***	.94
Y-axis acceleration ($m.s^{-2}$)	1.32 (0.49)	0.98[a] (0.37)	1.27 (0.53)	1.57[a] (0.74)	1.22[a] (0.55)	1.25 (0.52)	1.19[a] (0.46)	1.15[a] (0.57)	1.23 (0.60)	17.58***	.66
Z-axis acceleration ($m.s^{-2}$)	10.80 (3.79)	6.67[a] (1.82)	9.60[a] (3.35)	11.99[a] (4.72)	10.38 (3.41)	10.59 (3.66)	10.68 (3.75)	10.36 (3.78)	10.13[a] (3.59)	37.85***	.81
RMS Jerk ($m.s^{-3}$)	11.01 (3.88)	6.55[a] (1.78)	9.64[a] (3.36)	11.83[a] (4.21)	10.49 (3.47)	10.79 (3.86)	10.95 (3.96)	10.22[a] (3.85)	10.32[a] (3.63)	42.51***	.82
Smoothness	56.80 (14.31)	49.17[a] (14.04)	58.80 (15.01)	45.46[a] (11.78)	56.34 (14.37)	53.96[a] (17.79)	54.70[a] (14.65)	56.12 (14.77)	57.05 (15.00)	11.09***	.55

Table 2.1: Mean *(SD)* of the measure of each pressure condition. Note: [a] indicates significant difference from control condition. ***$p < .001$, ** $p < .01$

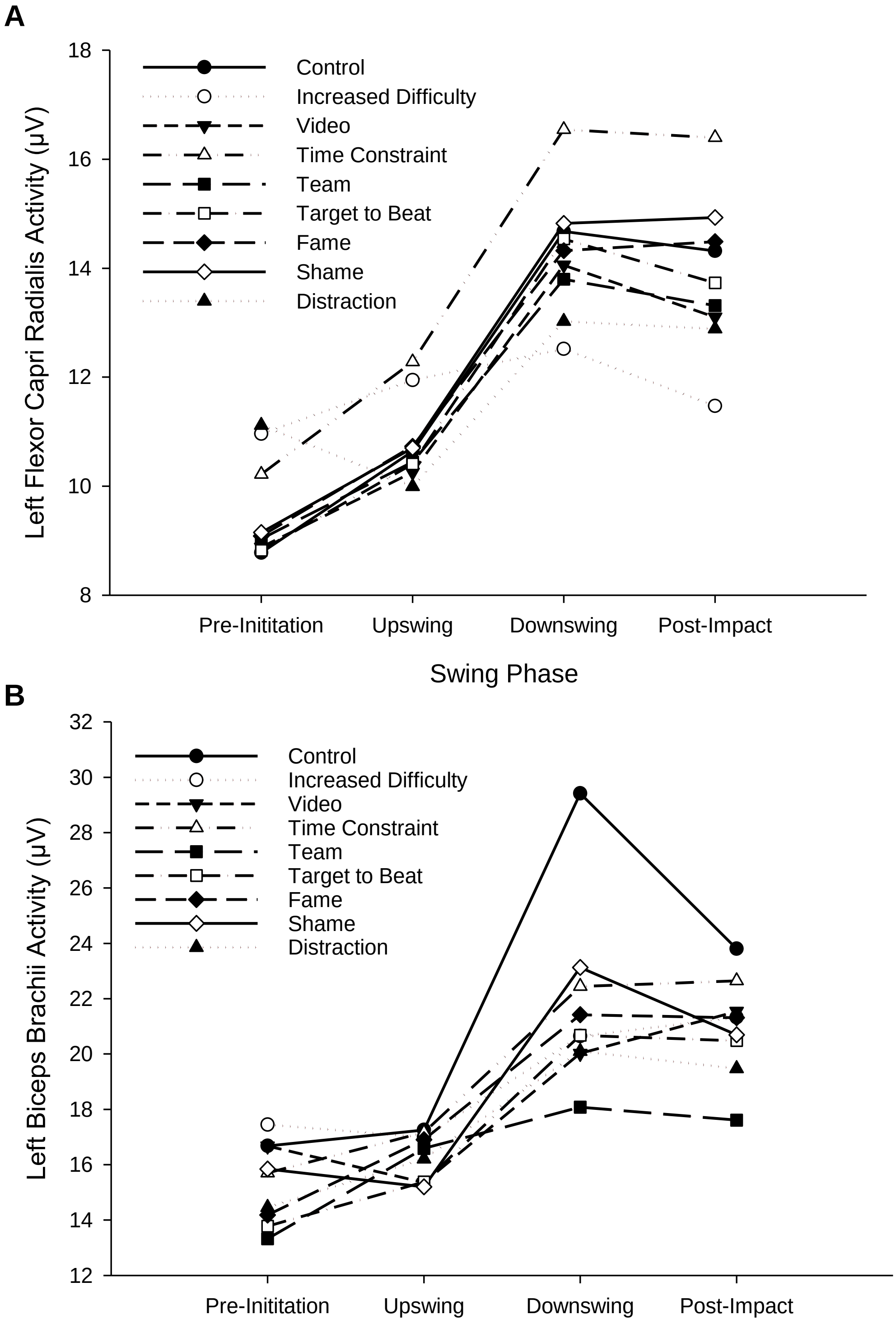

Figure 2.1: (A) Left flexor capri radialis muscle activity and (B) left biceps brachii muscle activity during each phase of the swing for control and eight pressure conditions.

Discussion

Evidence regarding how different isolated pressures can influence performance is needed to better understand the mechanisms underlying choking under pressure. The present research measured psychological, performance, physiological, and kinematic responses to a series of isolated pressure conditions. In comparison to control, perceived pressure increased in all conditions except the distraction condition. Accordingly, seven out of the eight experimental conditions successfully created pressure through consequence and demand-based scenarios. The effects of pressure on measured variables are discussed below.

Effects of Pressure on Psychological Measures

Except the distraction condition, all pressure conditions effectively caused changes to self-report data compared to control. The distraction condition, which employed a series of random but gradually more obtrusive noises, may not have induced psychological changes associated with increased pressure because the disruption was not sufficient. Although the methodology for this condition was consistent with the definition presented by Driskell *et al.*, (2001); that noise is '*unwanted sound which is unpleasant, bothersome, interferes with task activity, or is perceived as being potentially harmful'*, previous studies which have induced pressure through noise distraction, used a louder and more consistent sound (Stoker *et al*., 2017); a contrasting difference to the present research which could explain the null finding.

Conscious processing was used in this study as a direct indicator of reinvestment tendencies which are implicated in choking under pressure (Baumeister's, 1984). Conscious processing was found to increase across all conditions compared to control, except for the time constraint condition where it decreased. As conscious processing requires time, it is logical that this measure would decrease where time is limited. However, the theory that increased conscious processing is mechanistic of choking under pressure is not fully supported by the present findings, as performance was found to increase in some conditions where conscious processing was greater.

An increase in perceived pressure was accompanied by greater effort across all conditions, which is reflective of previous work (Wilson, 2008). This finding may demonstrate the relationship between pressure, anxiety, effort, and performance, and therefore supports the processing efficiency model of choking (Eysenck & Calvo, 1992). In this respect, the current findings suggest that auxiliary capacity was consumed beyond an ability to retain on-task attention in three out of the eight pressure conditions where performance decreased. However, overcoming pressure induced anxiety by maintaining efficient processing through an increase in effort, helped participants continue performing effectively in four conditions relative to control. Taken together, it is clear that further consideration is required to ultimately disentangle choking under pressure and the effect different isolated pressures may have on psychological variables.

Effects of Pressure on Performance

In line with the hypothesis, isolated pressures had different effects on performance. The effects for holed putts and mean radial error were also different. Mean radial error showed that participants were more accurate in four out of the eight conditions compared to control, but that they did not hole more putts in these conditions. Conversely, a decrease in mean radial error in two conditions compared to control, did correspond with participants holing less putts.

These results are similar to previous findings, in that performance has been shown to both improve and worsen in response to different laboratory pressures (Cooke *et al*., 2010, 2011, 2014; Mullen & Hardy, 2000; Wilson *et al*., 2007). However, in contrast to the hypothesis that all consequence and demand-based conditions would affect performance, outcome performance was only found to be worse in the two demand-based conditions (increased difficulty and time constraint) and one consequence-based condition (video). Although previous literature indicates that consequence-based conditions are more likely to induce pressure (Stoker *et al*., 2019), in line with the current study, Stoker *et al*., (2017) found performance was only impeded when the task became more difficult. Video was the only consequence-based condition where a performance detriment was recorded. This finding is consistent within the literature (Lawrence *et al*., 2014; Mesagno *et al*., 2011; Stoker *et al*., 2019) where evaluation-based pressures have long been associated with choking under pressure.

Likewise, competition has been a popular method for applying pressure in previous research (Stanne *et al.,* 1999). The anxiety one feels prior to competition is recognised to be greater in individual than team sports (Martin & Hall, 1997), thus performance in the fame and shame conditions could have been affected by the anxiety to compete as an individual. However, financial incentive is another prevalent method of manipulating pressure, and was the main rationale for the fame and shame conditions in the present study. Unlike previous research (Wilson *et al*., 2006; Cooke *et al*., 2010, 2011), performance was not influenced by a monetary reward. With past studies offering greater rewards when choking under pressure was reported though, perhaps the financial incentive was not great enough in the present research to detrimentally affect performance. In contrast, when participants faced losing money as a performance-contingent punishment, performance accuracy increased. This finding reflects Bell *et al*., (2013), who presented the idea that punishment may be more influential on performance than reward.

In comparison to the control condition, performance was also adversely affected under the pressure of a time constraint. As novice participants are more reliant on conscious motor planning processes for successful skill execution (Beilock *et al.,* 2004), time limitations could have disrupted performance because participants did not have adequate time to process the necessary information, plan/programme the movement, and/or controllably execute the skill. In contrast, in all other conditions compared to control, as expected participants took longer to perform. Further support for this explanation is offered by Nieuwenhuys *et al.*, (2008) where novice climbers were found to carry out longer-lasting movements in response to pressure. In summary, these findings confirm the hypothesis that the effect of different isolated pressures on performance are not equal.

Effects of Pressure on Physiological Measures

As hypothesised, HR increased with pressure. Although changes in this physiological index of arousal/anxiety were small, a significant finding is supported by previous multidisciplinary studies (Cooke *et al*., 2010, 2011 Pijpers *et al.,* 2005; Nieuwenhuys *et al*., 2008; Stoker *et al.*, 2017). The small cardiac reaction in some pressure conditions may be explained by the effect of a standing posture, as standing can cause cardiac reactivity to be blunted under stress (Veldhuijzen van Zanten *et al*., 2005). Alternatively, whilst the task was designed to require only low levels of physical exertion with limited postural changes, the psychological implications of cardiovascular findings must always be viewed with an air of caution, as unintentional small changes in energy expenditure could also explain these findings. In particular, perhaps the increased HR compared to control in the time constraint condition, was a result of greater physical exertion in response to participants swinging the club faster. This notion is supported by recent research which suggests that demand-based pressures alone do not affect HR, and consequences may be required to psychologically induce a physiological change (Stoker *et al*., 2017). Moreover, HR did not change in the other demand-based pressure condition (increased difficulty) compared to control. This is in contrast to previous literature (Carroll *et al.,* 1986) where task difficulty was found to influence cardiovascular reactions. However, an increased HR in conditions where an element of competition was applied mirrors existing work (Veldhuijzen van Zanten *et al.,* 2002), where competition was found to increase HR relative to an individual and cooperative competitive task. In combination, these findings suggest that psychologically derived changes in HR may be dependent on the type of isolated pressure scenario, and thus, different isolated pressure manipulations can elicit different effects on HR.

The psychophysiological correlate of effort (SDNN; HRV in the md-frequency band - Mulder, 1992) only changed compared to control in response to the time constraint and target to beat conditions. An increase in SDNN in the target to beat condition is representative of less effort, which is contradictory to self-report findings, and thus, may be more indicative of an increase in respiratory volume under pressure (Jorna, 1992). Conversely, a decrease in SDNN in the time constraint condition reflects an increase in effort, but whether this increase is physiological or psychological in nature remains unclear. The time constraint condition caused participants to swing the putter faster, and therefore potentially exhibit greater physicality. As such, SDNN may have decreased in the time constraint condition due to increased physiological demands. The secondary correlate of HRV which focused on the high frequency band (r-MSSD) did not change with the addition of pressure. No changes in r-MSSD despite self-reported effort increasing in all but one pressure condition, mirrors the findings of Cooke *et al.*, (2010, 2011) and Wilson *et al*., (2007). Taken together, these consistent observations suggest that HRV may not be a reliable measure of mental effort in this area of research.

Contrary to the hypothesis and previous findings (Cooke *et al*., 2010; Weinberg & Hunt, 1976), muscle tension did not change with pressure. Although a main effect of pressure condition was observed for left extensor carpi radialas activity, EMG was only found to differ in the time constraint condition compared to control. An increase in this condition is likely due to participants having to grip the club tighter to enable a faster movement. Contrastingly, no effects were found for pressure on left biceps brachii activity, which corresponds to previous findings in novice golf putting (Cooke *et al*., 2011). Experts have been shown to activate their extensor carpi radialis more than their biceps brachii (Smith *et al*., 2000; Stinear *et al*., 2006). The novice cohort in the present study exhibited the opposite. Therefore, it is possible that increased baseline levels of over-contraction in the novice cohort could have masked pressure related changes. Moreover, activity at both muscle sites was established to increase as a function of swing phase. Each successive movement requiring new recruitment of motor units may have created a cumulative effect on activity, hence pressure effects could have been further overridden by the physical demands of putting. Although muscle activity is considered a key component of successful putting performance (Smith *et al*., 2000; Stinear *et al*., 2006), it is unclear whether the effect of isolated pressure on muscle activity are equal in novice participants.

Effects of Pressure on Kinematic Measures

The hypothesis that movement kinematics of the putting stroke would be disrupted under pressure was supported. Previous research implicates changes in putting kinematics as a mediator of performance (Cooke *et al*., 2011). In particular, an increase in lateral acceleration has been suggested as a main determinant of impaired putting performance under pressure. These findings are contradictory to the present study, where number of holed putts decreased in the video and increased difficulty conditions despite participants creating a swing that was more likely to result in a squarer face angle and path through decreased lateral acceleration. Unlike Cooke *et al.*, (2011), pressure affected impact velocity (Z-axis acceleration) in conditions where performance detriments were recorded. For example, participants swung the club slower on a back-and-forth plane in the video and increased difficulty condition, which may have resulted in putts being under struck, and thus, could account for fewer holed putts compared to control. This concept is further supported by a significant increase in Z-axis acceleration in the time constraint condition. Participants holing less putts in this condition was likely to have been caused by overhitting balls as a result of swinging faster to account for the time limit. Nonetheless, decreased lateral acceleration could explain improved accuracy in three pressure conditions and contrastingly offer further support for Cooke *et al*., (2011). Perhaps an increase in conscious processing facilitated less lateral movement in conditions where accuracy improved, and participants were resultantly able to plan, programme, and execute a more accurate face angle and stroke. However, where a slower back-and-forth movement accompanied a decrease in lateral acceleration, and participants therefore had more time to consciously adapt the swing plane throughout the putting stroke, an increase in conscious processing may have become counterproductive and negatively disrupted movement kinematics. This suggestion is similar to studies conducted in climbers (Pijpers *et al*., 2005; Nieuwenhuys *et al*., 2008) where novice participants were found to produce more and longer-lasting movements under pressure. In summary, these findings confirm that different isolated pressures did not affect kinematic variables equally.

Limitations of the Study and Directions for Future Research

These results should be interpreted in light of some methodological limitations. Firstly, choking under pressure in sport normally occurs over one trial (e.g., you might only get one chance to hole a major winning putt), the present study averaged performance over five repetitive putts. However, with single trial performance generally resulting in large variability and poor reliability (e.g., Woodman & Davis, 2008), this number was used as a compromise between ecological validity and measurement reliability, and reflects previous work by Cooke *et al.*, (2010). Despite this rationale, the effects of pressure may have been diluted due to this multiple trial framework, as participants had a greater opportunity to overcome anxiety and perform subsequently better with each putt. Secondly, given that the current study aimed to better understand the psychophysiological and performance effects of isolated pressures, some conditions did not test a singular pressure. For example, although fame and shame conditions affected a multitude of variables compared to control, these conditions contained themes of competition, evaluation, and financial incentives. However, given that the pressure experienced in a laboratory environment is likely to be less than athletes face in real-life competition (see Baumeister & Showers, 1986), it was a priority of this study to ensure that fabricated pressure was of an adequate level to be ecologically valid. Nonetheless, the purpose of this study was to explore whether differently derived pressures have equal effects, and the addition of concurrent themes to certain conditions may have compromised the results relative to this aim.

In line with popular theories of choking, future studies exploring how isolated pressure can affect participants from a multi-disciplinary approach could focus on further disentangling the relationship between attention and performance. More specifically, expanding on previous psychophysiological research (Lacey & Lacey, 1974) where HR deceleration has been linked to attentional processes. These advancements could not only support mechanistic theories associated with choking under pressure, but could also lead to the eventual development of more objective training methods aimed at alleviating incidences of choking under pressure.

Conclusion

By concurrently assessing performance, psychological, physiological and kinematic measures to isolated pressures, the current findings challenge the assumption that all pressures are equal and additive (Baumeister, 1984). Taken together, our findings indicate that different consequence and demand-based pressures exert different effects on various processes implicated with successful skilled motor performance.

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CHAPTER THREE

The Psychophysiological Effects of Task Difficulty on Experienced Performance; The Relationship Between Attentional Processes and Cardiac Patterns Preceding Skilled Motor Performance

Abstract

Expert performers have been established to exhibit heart rate deceleration in the seconds prior to the execution of a target-based motor skills (Cooke *et al*., 2010; Cotterill & Collins, 2005; Neumann & Thomas, 2009). Preparatory bradycardia is proposed to be indicative of external focus of attention (Lacey & Lacey, 1970, 1974, 1980). Although this heart rate slowing phenomenon is well documented, understanding regarding the relationship between pre-performance cardiac deceleration and attentional processes remains limited. Under the premise that increased task difficulty requires greater attentional processes, and thus could potentially affect preparatory bradycardia, 40 experienced golfers completed baseline and seven counterbalanced putting conditions. Conditions were designed to manipulate difficulty, by altering putt distance, hole size, and surface gradient. A series of repeated measures ANOVAs indicated that performance was significantly affected by condition difficulty. Similarly, condition difficulty affected several aspects of the cardiac pattern, including the magnitude of heart rate deceleration and the rate of the heart rate deceleration. Correlative analysis revealed the rate of heart rate deceleration to be the strongest correlate of the two performance measures. In sum, the rate of deceleration was respectively quicker and slower in easier and more difficult conditions. These findings help improve our understanding of the attention-performance relationship and suggest that attention efficiency may be important for performance.

Introduction

In self-paced sports such as golf, attentional processes have emerged as a key component of expertise (Abernethy *et al*., 2007; Wulf, 2007). It is in the interest of optimised sports performance therefore, to identify methods of maintaining and/or improving attentional focus. Psychophysiological methods provide a concurrent and relatively unobtrusive measure of performance-related processes, and thus, provide researchers with an opportunity to objectively explore how attentional processes may link to the physiological processes of skilled motor performance (Abernethy *et al*., 2007; Collins 2002).

A short-term phasic pattern of heart rate (HR) deceleration is well-documented in the seconds preceding skilled motor tasks, such as golf (Cotterill & Collins, 2005; Neumann & Thomas, 2009), pistol shooting (Tremayne & Barry, 2001), and rifle shooting (Hatfield *et al*., 1987). This bradycardia has been identified as a psychophysiological marker of attentional focus (Lacey & Lacey, 1970, 1974, 1980). Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis suggests that this HR deceleration pattern is associated with decreased feedback to the brain which often results in superior performance as a result of more effective external focus of attention. More specifically, HR deceleration causes a reduction in blood pressure, which increases flow of environmental information to the brain by unloading the baroreceptors (Brunia, 1993). Conversely, an increase in HR is believed to cause a promotion of the bulbar restraint upon the reticular formation, which can reduce the cortical response to external stimuli. Thus, where HR acceleration is detected, this visceral afferent feedback model suggests environmental cues are not as impactful (Hatfield *et al*., 1987). Common interpretations of this phenomenon derive from early reaction time paradigm studies by Lacey and Lacey (1970), where a systematic HR deceleration was noted during a fixed foreperiod between a ready signal and imperative signal. Another initial study exploring anticipatory HR between the 'Get Set' – 5 s delay – 'Go' command, found that participants exhibited HR acceleration until 1 s before the 'Get Set' command, then HR deceleration until 1 s before the 'Go 'command in anticipation of climbing a flight of stairs or performing a bicycle sprint (Stern, 1976). More recently, applied sports performance studies (Cotterill & Collins, 2005; Neumann & Thomas, 2009) have suggested that HR deceleration immediately prior to task execution indicates that athletes have engaged their attention in external factors as part of the planning and programming phases of preparation for action. In golf putting for instance, these factors may include focusing attention on the anticipated path of the ball towards the hole, the hole itself, or the clubhead either in the stationary address position or during the putting stroke.

The above examples are generally deemed as external focus points. Self-focus mechanistic theories of choking under pressure (Baumeister, 1984; Masters, 1992) and the constrained action hypothesis (Wulf & Prinz, 2001) help explain the benefits of focusing on external cues. For instance, enhanced performance and learning are often facilitated by external focus of attention as it encourages automatic control processes. Wulf *et al.*, (2007) demonstrated these principles in a two-part study on novice and expert golfers. In the first experiment, novice participants who learnt a golf skill using external cues showed greater skill retention than the internal focus or control groups. Whilst in the second experiment, expert golfers performed better when asked to focus on the pendulum-like motion of the club (external focus of attention) rather than the swinging motion of their arms (internal focus of attention). Moreover, the benefits of external focus appear to increase with task complexity (Landers *et al.*, 2005). In contrast, focusing attention internally tends to lead to an increase in conscious processing which actively influences movement control, and thus, causes automatic motor control processes to be disrupted. Reinvestment theory in particular, suggests that these processes may be more prevalent in performers under pressure and has been proposed as a mechanism for athletes 'choking under pressure' (Baumeister, 1984). As HR deceleration is synonymous with external focus of attention (Neumann & Thomas, 2011), the link between this phasic cardiac pattern and conscious processing/reinvestment warrants further exploration.

HR deceleration has been observed in both expert and novice populations. However, concurrent with the notion that external focus of attention is more prevalent in expert performance (Fitts and Posner, 1967), preparatory bradycardia has been found to be more pronounced in groups with greater levels of skill acquisition (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009). For example, Boutcher and Zinsser (1990) found that expert and novice golfers respectively reduced their HR during the four interbeat intervals preceding 12-ft putts by 20 beats per min (bpm) and 15 bpm. Neumann and Thomas (2009) similarly found that elite, experienced, and novice golfers, exhibited HR deceleration of 12, 10, and 2 bpm respectively during the 6 s preceding 8-ft putts, whilst Cooke *et al*., (2014) observed a deceleration of 20 bpm for experts, and 9 bpm for novices in the 6 s before participants completed a 2.4 m putt. Conversely, Konttinen *et al*., (1998) observed a greater HR deceleration in less-skilled shooters than highly skilled shooters. Given the relationship between external focus of attention and expertise, this finding somewhat questions the validity of HR deceleration as an index of optimal attentional focus. However, in this case, the physicality of postural stability may have undermined the results. Accordingly, the literature suggests that a greater magnitude of pre-performance HR deceleration seen in experts, may indicate a greater engagement in preparatory external information processing (Neumann & Thomas, 2009).

Moreover, although these studies highlight differences between expert and novice preparatory cardiac activity, they also demonstrate a number of similarities in terms of the HR deceleration pattern. In golf putting for example, generally there is an acceleration phase before HR deceleration starts around 3-6 s before impact with the ball. Following impact with the ball, HR then accelerates to match baseline levels (Cooke *et al*., 2014, Neumann & Thomas, 2009; 2011). However, experts exhibit more pronounced and earlier HR acceleration compared to novices in terms of this observed pre-impact acceleration phase. Furthermore, experts begin HR deceleration around 6 s prior to ball impact, with the lowest HR recorded at the epoch closest to ball impact. HR then begins accelerating towards baseline levels immediately after impact with the ball, with pre-movement HR re-established around 6 s post-impact in expert performers. Conversely, pre-impact HR deceleration in novice participants tends to begin later at around 3 s before impact. HR then remains close to the lowest level until a few seconds after impact, at which point HR acceleration is initiated. Despite the delay in post-impact acceleration phase compared to experts, because the magnitude of HR deceleration is less in novices, HR still returns to baselines levels around the same time as experts (approx. 6 s post-impact). Based on Lacey and Lacey's (1970, 1974, 1980) interpretation of these HR changes, the earlier onset of HR deceleration in expert participants may be a result of more effective encoding of environmental information and/or greater focus on external cues (e.g., ball, aim line, and hole). Conversely, the initial HR acceleration phases observed as part of preparatory cardiac activity has been associated with internal focus of attention (Radlo *et al*., 2002), and suggests novice and expert performers consider how their body needs to move to execute a successful performance as part of pre-performance routines. Further support for the notion that cardiac acceleration is indicative of internal attentional processes in skilled motor performance, is apparent in studies which extend the post-impact recording time (Neumann & Thomas, 2009). As well as a pre-impact HR acceleration phase, experts have also been shown to exhibit significant HR acceleration (above baseline levels) post-impact, peaking around 8 s after hitting the ball. As novices do not exhibit this pattern, experts may employ their greater technical understanding and use the time immediately after a putt to internally analyse and learn from their previous performance. In combination, this body of work suggests that cardiac oscillations seen in the seconds before and after skilled motor tasks may characterise attentional processes associated with preparation for action.

In line with the research and theorising of Lacey and Lacey (1970, 1974, 1980), these findings have been interpreted as a physiological indication that experts process external information by focusing on environmental stimuli during the seconds preceding skilled-motor execution. This interpretation is intuitively attractive since it is necessary for athletes to locate and process a target prior to skilled-motor execution to be successful in aiming sports. It is also consistent with visual activity research, which has confirmed that experts fixate their eyes, and presumably their attention, on external cues prior to shot execution (e.g., Vine *et al*., 2013; Wilson, *et al*., 2009). Duration of fixation on a target in the seconds preceding movement has been termed quiet eye duration (Vickers, 1996), with parameters, such as movement programming postulated to occur during this time. With quiet eye research arguing that longer quiet eye periods lead to better performance, and the fact that attentional processes are suggested to be longer for more complex tasks (Henry & Rogers 1960), it is logical to deduce that quiet eye duration may lengthen as a function of task difficulty (Walters-Symons *et al.*, 2018).

As shown by Salazar *et al.,* (1990) though, not all studies have witnessed phasic cardiac effects in the seconds preceding skilled motor task execution. Whilst Salazar *et al*., (1990) null findings could be attributed to the physical strain associated with holding a fully drawn bow weighing the equivalent of 14-22 kg placing greater demands on the cardiovascular system, and therefore overriding potential HR deceleration, it is also prudent to consider whether these phasic HR changes may be a result of non-attentional factors. Although in agreement with Lacey and Lacey (1970, 1974, 1980) regarding the occurrence of HR deceleration in skilled motor tasks, Obrist (1968) suggested that the underlying mechanism for the observed cardiac pattern was due to reduced muscle and metabolic activity. Similarly, the established relationship between respiration and HR must be considered in this area of research. With HR deceleration naturally accompanying exhalation (respiratory sinus arrythmia), it remains difficult to completely rule out respiratory influences on this cardiac phenomenon. It should also be noted that inconsistent findings concerning HR deceleration could be an artefact of high inter- and intra-individual variability (e.g., Lykken *et al.,* 1966). This may render some studies underpowered to detect effects. Although a number of studies examining Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis exist, further exploration is ultimately required to determine whether HR deceleration in seconds preceding skilled motor performance is indicative of attentional processes.

Despite a mounting body of research confirming the presence of this cardiac pattern (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Cotterill & Collins, 2005; Hatfield *et al*., 1987; Neumann & Thomas, 2009), little work has been done to continue Lacey and Lacey's (1970, 1974, 1980) original laboratory-based studies aimed at disentangling the relationship between phasic HR deceleration and attentional processes. The limited psychophysiological research completed to date has focused on manipulation of participant attention by instructing the performer to adopt a particular focus of attention (Neumann & Thomas, 2011; Radlo *et al.,* 2002). For example, Neumann and Thomas (2011) found that attentional focus instructions had an effect on tonic cardiac activity but not phasic changes prior to participants executing a golf putt. In contrast, Radlo *et al*., (2002) found HR deceleration was more pronounced in novice dart throwing when participants were asked to focus their attention externally on the target compared to internally on their movements. In sum, although some features of this cardiac deceleration phenomenon are well established, it is unclear how this pattern of cardiac activity may change as a function of attentional focus in experienced performers.

Building on the literature reviewed above, the present study adopted a psychophysiological approach to further explore attentional focus and the HR deceleration phenomenon in experienced golfers. Under the premise that increased task difficulty would require greater attentional focus to perform successfully, the current work sought to examine how cardiac activity may change in response to more difficult and easier putting tasks. To help maintain ecological validity, a basic putting task was manipulated by altering distance from target, hole size, and putting surface profile. Given that participants would be required to pay more attention to the external environment on difficult putts in order to be successful, and thus, exhibit greater levels of external attentional focus, it was hypothesised that more difficult tasks would produce a greater magnitude of HR deceleration in the seconds preceding performance. In terms of performance, it was hypothesised that more difficult tasks would instigate a decline. Moreover, under the premise that increased conscious processing is strongly linked to participants exhibiting greater levels of internal attentional focus (which is believed to be detrimental to performance), an increase in conscious processing was also expected to decrease in conditions where performance worsened.

Method

Participants

31 male and 9 female right-handed sport and exercise science students participated in exchange for course credit. All participants (M age = 20.18 years, SD = 1.34 years) were regular golfers with on-course playing experience (M handicap = 17.34, SD = 14.39). The protocol was approved by the local research ethics committee and all participants provided informed consent.

Task

Participants performed a golf putting task. Similar tasks have been used in previous preparation for action studies (e.g., Cooke *et al.,* 2014; Neuman & Thomas, 2009, 2011). To be successful in this task, participants were required to accurately plan and program both movement force and direction, meaning that cognitive processes such as conscious processing and external focus of attention were likely to be prevalent in the seconds before execution.

Performance Measures

The primary outcome measure of performance was number of holed putts. A secondary measure of performance, mean radial error (i.e., average distance the ball finished from the hole), indicated participant accuracy and directional miss tendencies. Mean radial error was recorded as distance from the centre of the hole to the closest point of the ball.

Psychological Measures

Pressure and effort. Participants indicated whether they found the task difficult on a 7-point Likert scale, anchored by 1 "*not at all true*" and 7 "*very true*". Effort and pressure were measured using the 5-item effort/interest and pressure/tension subscales of the Intrinsic Motivation Inventory (Ryan, 1982). Participants used the same 7-point Likert scale to rate items like "*I tried very hard to do well*" for the effort subscale, and "*I felt pressured*" for the pressure subscale. The internal consistency of the effort (α = .80 to .91) and pressure (α = .94 to .98) subscales were very good across conditions. Effort was used to ascertain participant engagement and whether greater effort was associated with increased task difficulty, whilst feelings of pressure have been associated with more difficult tasks (Carroll *et al*., 1986).

Conscious processing. The putting-specific conscious processing scale (Cooke *et al.*, 2011) was used to explore the relationship between cardiac deceleration and attentional processes (Lacey & Lacey, 1970, 1974, 1980). After each condition, participants used a 5-point Likert scale anchored by 1 "*never*" and 5 "*always*" to indicate how they mentally approached the previous putts (e.g., "*I thought about my putting stroke*", "*I tried to figure out why I missed putts*"). The internal consistency of the scale was very good (α = .80 to .88).

Physiological Measures

Cardiac. An electrocardiogram was recorded using three silver/silver chloride spot electrodes (Cleartrace, ConMed, Utica, NY) in a modified chest configuration. The signal was amplified (Delysys® Bagnoli-4 EMG system, Boston, MA), filtered (1-100 Hz), and digitalized at 2500 Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK) using Spike2 software (Cambridge Electronic Designs). Although R-wave peaks were automatically identified by an interactive program, visual inspection and manual movement of R-wave peaks ensured correct scoring of the analog electrocardiographic signals. R-R interval analysis confirmed tonic HR (Heart Rate) and two-domain indices of HR variability (SDNN; standard deviation of R-wave to R-wave intervals, r-MSSD; root mean square of successive R-R intervals).

HR was also calculated for each 0.5 s epoch from 10 s before impact with the ball to 5 s post-impact, which enabled a more specific investigation of the previously established cardiac deceleration phenomenon (Cooke *et al*., 2014; Neuman & Thomas, 2009, 2011). HR at impact corresponded with the lowest point of the deceleration curve in all conditions at a mean level, whilst change in HR reflected the magnitude of HR deceleration. Change in HR was calculated by subtracting HR at the epoch where the lowest HR occurred (i.e., 0 s), from the epoch where the highest HR occurred (i.e., where deceleration began) before impact with the ball in each condition. Finally, the rate of deceleration looked at the gradient of the curve, and was calculated by dividing the change in HR, by the time between the max and min points (accounting for conversion to mins to reflect the bpm unit of HR). These variables in combination indicated how quickly and to what extent HR decelerated in the seconds immediately before and after putting.

Muscle Activity. Muscle activity was continuously recorded at two sites via single differential surface electrodes (DE 2.1, Delsys®, Boston, MA) and an amplifier (Delysys® Bagnoli-4 EMG system, Boston, MA), with a ground electrode attached on the collar bone. Both the left flexor carpi radialis and right biceps brachii muscles have been implicated as mediators of sub-optimal putting performance (Smith *et al*., 2000; Stinear *et al*., 2006). EMG signals from these muscles were amplified, (Power 1401, Cambridge Electronic Design, Cambridge, UK), filtered (20-450 Hz), digitalized (2500 Hz), and recorded using Spike 2 software. The mean amplitude (microvolts) for each muscle during each condition was calculated by averaging total activity across all putts. Z-axis acceleration enabled EMG analysis during four separate swing phases: pre-initiation, upswing, downswing, and post-impact. The pre-initiation period was the same duration as the upswing movement. The upswing phase was signalled by the end of the pre-initiation phase, whilst the downswing period began once upswing had reached its maximum point in the “backswing”. The downswing lasted from this point until impact with the ball. The post-impact portion of the swing was the same duration as the downswing and begun immediately after impact with the ball.

Kinematic Measures

Movement Kinematics. A tri-axial accelerometer (ADXL337 Breakout, Cool Components, UK) was used to record clubhead acceleration in three planes. X, Z, and Y acceleration facilitated analysis of clubhead movements laterally, back-and-forth, and vertically. Impact between the ball and putter was registered by an impact sensor (Piezo Vibration Sensor, Measurement Specialties Inc, USA), which was attached to the clubhead shaft along with the accelerometer. Movement kinematics were determined during the time between the initiation of the downswing and impact with the ball. As the Z-axis is regarded as the primary clubhead movement in putting, it was also used to calculate derivate indices of kinematic efficiency; root mean square jerk (RMS Jerk) and smoothness (see Maxwell *et al.*, 2003). Mean values for each kinematic variable were computed by averaging values across all putts in each condition.

Conditions

The control condition required participants to putt nine standard sized golf balls (Pro V1, Titleist) 2 m to a standard sized golf hole (10.8 cm diameter), located centrally 1.25 m from the end of a flat 1.5 m x 5 m indoor artificial putting surface (Augin Turftiles), using a standard length (90 cm) steel-shafted blade style putter (Sedona 2, Ping, Phoenix, AZ). A putting distance of 2 m was chosen, because it is the approximate distance where USPGA professional golfers will on average successfully hole a putt around 70% of the time (http://www.pgatour.com). It is likely therefore that regular golfers will successfully hole a putt of this distance around 50% of the time. With task difficulty the main manipulation underpinning experimental conditions in this study, it was important to establish a control procedure where participants were equally likely to be successful or unsuccessful, thus instigating a balance between how easy or difficult the task was. The surface measured 4.27 m using a Stimpmeter, which is faster than most greens, as according to the US Golf Association readings will generally range from 2.13 m to 3.66 m on competitive courses. In addition to the control condition, task difficulty was manipulated under three sub-themes: distance from target, hole diameter, and surface profile.

In the distance from target conditions, participants putted under the same conditions as control, but from 3 m, 1 m and 50 cm away from target. Compared to the control distance (2 m), these were expected to be relatively harder, easier, and much easier, respectively. In the hole diameter conditions, participants putted under the same conditions as control, but the hole diameter was 50%

(5.4 cm) and 75% (8.1 cm) the size of a standard golf hole. Compared to the control hole diameter (100%; 10.8 cm), these were expected to be relatively much harder, and harder, respectively. In the surface profile conditions, participants putted on a sloped surface. In golf, undulating greens require additional aiming considerations, and movement planning and programming to account for the gravitational effects of ‘breaking putts’ on the ball. Participants were asked to putt under the same conditions as control, but with a left-to-right slope and right-to-left slope. Compared to the flat surface profile of the control condition, both sloped conditions were expected to be relatively harder.

Procedure

Due to potential influences on cardiovascular activity, participants were asked to refrain from consuming caffeine at least 4 h’s before their laboratory sessions. Upon entering the laboratory, skin sites were exfoliated and cleaned ready for attachment of electrocardiogram and EMG electrodes. Specialist electrode interfaces and medical tape ensured secure attachment and good quality signal output. Participants completed nine practice putts under control conditions to familiarise themselves with the putting surface and equipment. Using a within-participant design, a Latin square (Williams, 1949) was employed to counterbalance the order for completing all conditions, including the recorded control condition. No instructions or suggestions were given prior to, or during the experiment regarding putting technique. Participants were informed repeatedly throughout the experiment to complete putts at their own pace and reminded that performance would be assessed in terms of number of holed putts and mean radial error; therefore, they should not only aim to get the ball in the hole, but to finish it as close to the hole as possible. A £20 reward was offered for the best overall performer to encourage continued task engagement. The instructions for each condition were administered by the experimenter using a script. To help ensure consistency and eliminate any potential cardiac reactions to postural changes caused by participants bending over to place the ball on the putting surface themselves, the ball was placed in the designated position by the experimenter prior to each putt. Immediately after each condition, participants complete a post-condition questionnaire on a tablet computer to assess psychological measures. This process meant participants rested for approximately 3 min between conditions.

Statistical Analysis

The effects of task difficulty were explored using separate 8 condition repeated measures analyses of variance (ANOVAs). Post hoc pairwise comparisons (least significant difference) were employed to further examine how performance, psychological, physiological and kinematic measures changed with task difficulty in comparison to control. Significant differences were deemed to exist if comparative values were outside the 95% confidence interval. Moreover, this method of analysis was also used to confirm the effects of task difficulty within the three sub-themes; distance from target, hole diameter, and surface profile.

HR was subjected to an 8 condition x 31 epoch (i.e. -10 s, -9.5 s … to +4.5 s, +5 s) repeated measures ANOVA, and separate 3 or 4 condition x 31 epoch repeated measures ANOVA's within the three sub-themes of difficulty (Figure 3.1). Muscle activity was assessed using an 8 condition x 4 phase repeated measures ANOVA for each muscle site (Figure 3.2). To explore the relationship between performance and the bradycardia phenomenon, the three mean measures of HR deceleration (HR at impact, change in HR, and rate of HR deceleration) were correlated with the two mean performance measures within participants across conditions (Table 3.2 and 3.3). Fisher Z transformations were employed to determine average correlations. The average of these correlations was back transformed to a Pearson correlation coefficient, and the size of this coefficient tested for linear independence (i.e., compared with 0 using a t test), significance (using a table of critical values), and interpreted as small, medium, or large (Cohen, 1992).

Significant effects were reported using the multivariate method so the risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVAs was minimised (Vasey & Thayer, 1987). Partial eta-squared is reported as a measure of effect size, with values of .02, .12 and .26 indicating relatively small, medium, and large effect sizes respectively (Cohen, 1992).

Results

Effects of Task Difficulty on Performance Measures

The separate 8 condition repeated measures ANOVAs confirmed a main effect for task difficulty on number of holed putts and mean radial error (Table 3.1, top). Post hoc pairwise comparison analysis showed that compared to control, participants holed significantly fewer putts in the 3 m, 75% hole diameter, 50% hole diameter, and the left-to-right slope conditions. Perhaps unsurprisingly, accuracy (i.e., radial error) also significantly decreased in the same conditions. Conversely, performance both in terms of number of holed putts and mean radial error significantly improved in the 50 cm condition.

Effects of Task Difficulty on Psychological Measures

The separate 8 condition repeated measures ANOVA’s showed main effects for condition on all psychological measures (Table 3.1, middle). Changes in perceived task difficulty scores indicated that participants found the 3 m, the 75% hole diameter, the 50% hole diameter, the right-to-left slope, and left-to-right slope conditions more difficult than control, whilst the 50 cm condition was easier. In line with the experimental design rationale, these analyses confirm successful manipulation of task difficulty. Post-hoc pairwise comparisons also revealed that effort increased in the 50% hole diameter, and left-to-right slope condition, compared to control. In contrast, participants reported a decrease in effort for the 1 m and 50 cm condition. Conscious processing increased in the 3 m and 50% hole diameter conditions, but decreased in the 50 cm condition. Meanwhile, perceived pressure only changed (increased) in the 1 m condition relative to control.

Effects of Task Difficulty on Physiological Measures

A cardiac profile of HR deceleration in the seconds before participants struck the ball was confirmed by an 8 condition x 31 epoch repeated measures ANOVA. Both a condition, $F(7,33) = 3.68$, $p < .01$, $\eta^2 = .44$, and epoch effect, $F(30,10) = 14.94$, $p < .001$, $\eta^2 = .98$, was observed. Figure 3.1

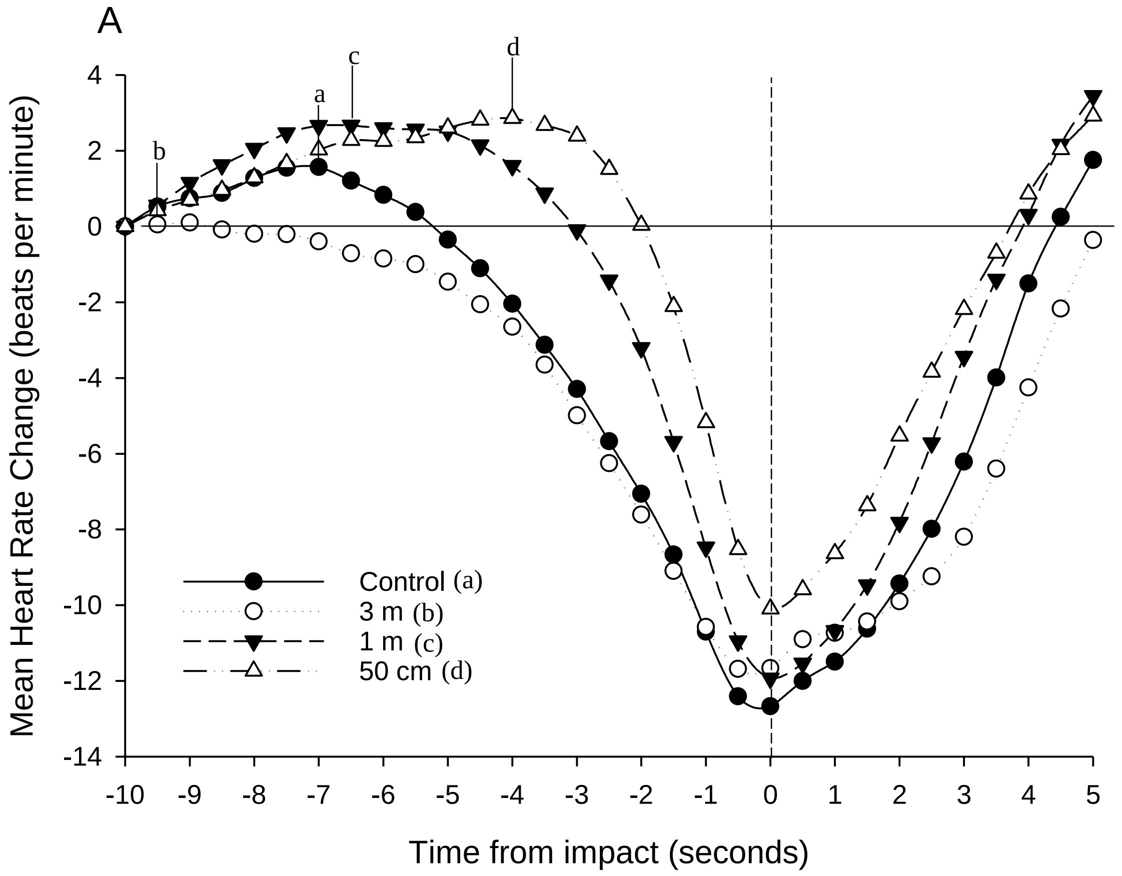
shows the mean change in heart rate compared to control for the three sub-themes of difficulty. Distance from hole, *F*(37,3) = 10.05, $p < .001$, $\eta^2 = .45$ was the only sub-theme where condition was found to have a main effect on HR. Condition did not affect HR in the diameter of the hole conditions, *F*(38,2) = 0.21, $p = .81$, $\eta^2 = .01$, or the putting surface profile conditions, *F*(38,2) = 1.46, $p =.25$, $\eta^2 = .07$ relative to control. The separate 8 condition repeated measures ANOVAs showed that task difficulty had no effect on HR variability measures or HR at impact. However, main effects of condition were found for HR, change in HR, and rate of HR deceleration (Table 3.1, middle). Compared to control, pairwise comparisons revealed that tonic HR was lower in the 50% hole diameter, the right-to-left slope, and the left-to-right slope conditions. The rate of HR deceleration also changed in response to task difficulty. Compared to control, pairwise comparisons showed that deceleration was slower in the 3 m and the 50% hole diameter conditions. Conversely, the rate of HR deceleration was quicker in the 50 cm condition. Moreover, tables 3.2 and 3.3 indicate that the rate of heart rate deceleration was strongly related (i.e., large effect size) to the number of holed putts, *r*(6) = --.58, $p = .07$, and mean radial error, *r*(6) = .48, $p = .11$. The change in heart rate was moderately related (i.e., medium effect size) to holed putts, *r*(6) = -.28, $p = .25$, and mean radial error, *r*(6) = .23, $p = .29$. Heart rate at impact was weakly related (i.e., small effect size) to holed putts, *r*(6) = -.16, $p = .35$, and mean radial error, *r*(6) = .11, $p = .40$. In sum, performance was better – more putts were holed and putts finished closer to the hole – when heart rate decelerated faster.

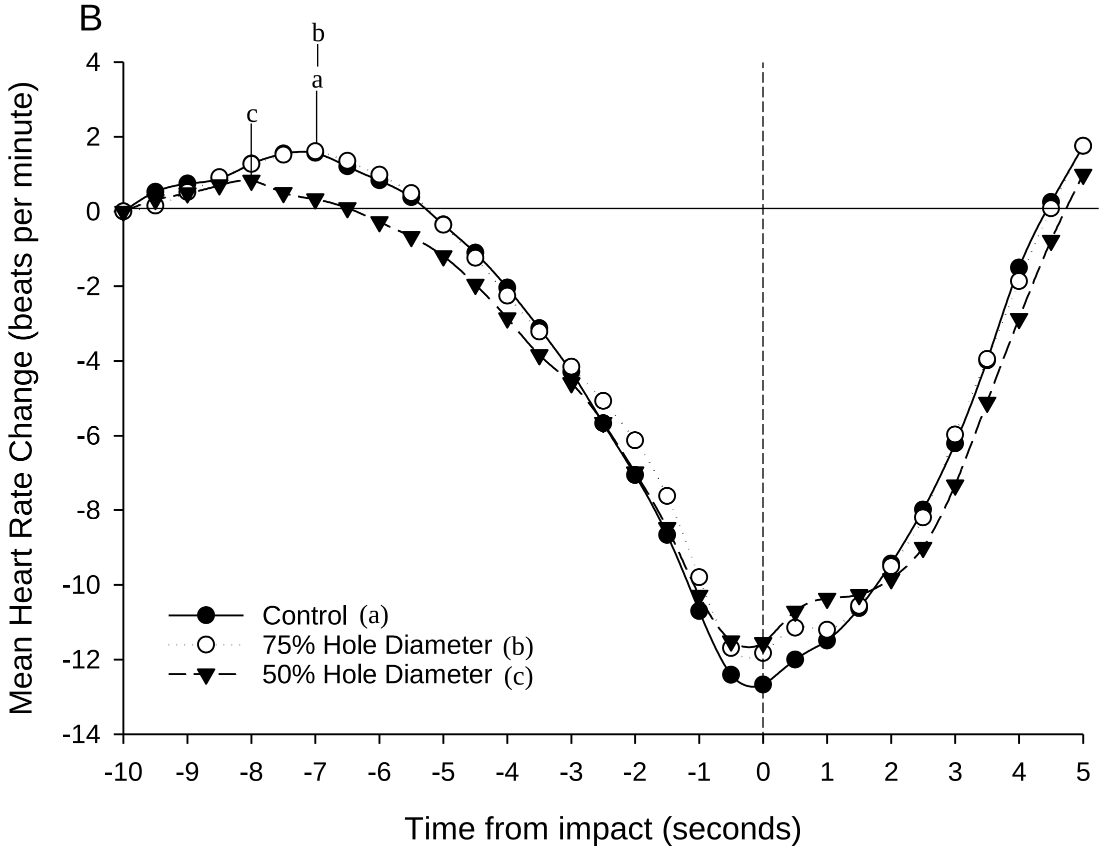
In terms of muscle activity, although the separate 8 condition repeated measures ANOVAs revealed no main effect for condition on average EMG at either muscle site, separate 8 condition x 4 phase repeated measures ANOVAs showed that muscle activity was affected by swing phase for the left flexor carpi radialas, *F*(3,37) = 7.07, $p < .01$, $\eta^2 = .36$, and the right biceps brachii, *F*(3,37) = 8.22, $p < .001$, $\eta^2 = .40$ (Figure 3.2). For the left flexor carpi radialis, this represented an increase in muscle activation between the pre-initiation and upswing phases, *F*(1,39) = 21.72, $p < .001$, $\eta^2 = .36$. EMG then decreased between the upswing and downswing phases, *F*(1,39) = 14.27, $p < .001$, $\eta^2 = .27$, before remaining constant between the downswing and post-impact phases, *F*(1,39) = 0.09, $p = .77$, η^2

= .002. In contrast, no change was seen in muscle activity between the pre-initiation and upswing phases of the swing for the right biceps brachii, $F(1,39) = 0.22$, $p = .65$, $\eta^2 = .005$, but an increase was observed between the upswing and downswing phase, $F(1,39) = 17.25$, $p < .001$, $\eta^2 = .31$. Tension was then maintained between the downswing and post-impact phases, $F(1,39) = 0.04$, $p = .85$, $\eta^2 = .001$. No condition or condition x phase effects were found for either muscle site.

Effects of Task Difficulty on Movement Kinematics

Separate 8 condition repeated measures ANOVAs revealed main effects for all movement kinematic measures (Table 3.1, bottom). Compared to control, pairwise comparisons analyses revealed that participants exhibited greater X-axis acceleration in the 3 m, the right-to-left slope, and left-to-right slope conditions. Whereas in the 1 m, the 50 cm, the 75% hole diameter, and the 50% hole diameter conditions, X-axis acceleration. In sum, where a longer swing was required to account for greater distance, and/or the task was perceived to be more difficult, lateral movement was generally found to increase. Z-axis acceleration followed a similar pattern with participants generally increasing speed of putting stroke in the 3 m, the right-to-left slope, and the left-to-right slope condition, compared to control. Z-axis acceleration conversely decreased in the 1 m, the 50 cm, the 75% hole diameter, and the 50% hole diameter conditions. A condition effect was also observed for Y-axis acceleration. Compared to control, Y-axis acceleration increased in the 3 m, and the left-to-right slope conditions. In contrast, Y-axis acceleration was found to decrease in the 1 m and the 50 cm condition. As such, vertical clubhead movement was typically found to be greater in conditions where participants perceived the task to be more difficult. In terms of the Z-axis derivate, RMS jerk, pairwise comparisons showed that RMS Jerk increased in the 3 m, the right-to-left slope, and the left-to-right slope conditions, compared to control. Whereas in the 1 m, the 50 cm, the 75% hole diameter, and the 50% hole diameter condition, RMS jerk decreased. Smoothness, the second derivate of Z-axis acceleration, decreased in the 1 m, the 50 cm, the right-to-left slope, and the left-to-right slope condition compared to control.


A
Mean Heart Rate Change (beats per minute)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time from impact (seconds)
a
b
c
d
Control (a)
3 m (b)
1 m (c)
50 cm (d)


B
Mean Heart Rate Change (beats per minute)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time from impact (seconds)
b
a
c
Control (a)
75% Hole Diameter (b)
50% Hole Diameter (c)

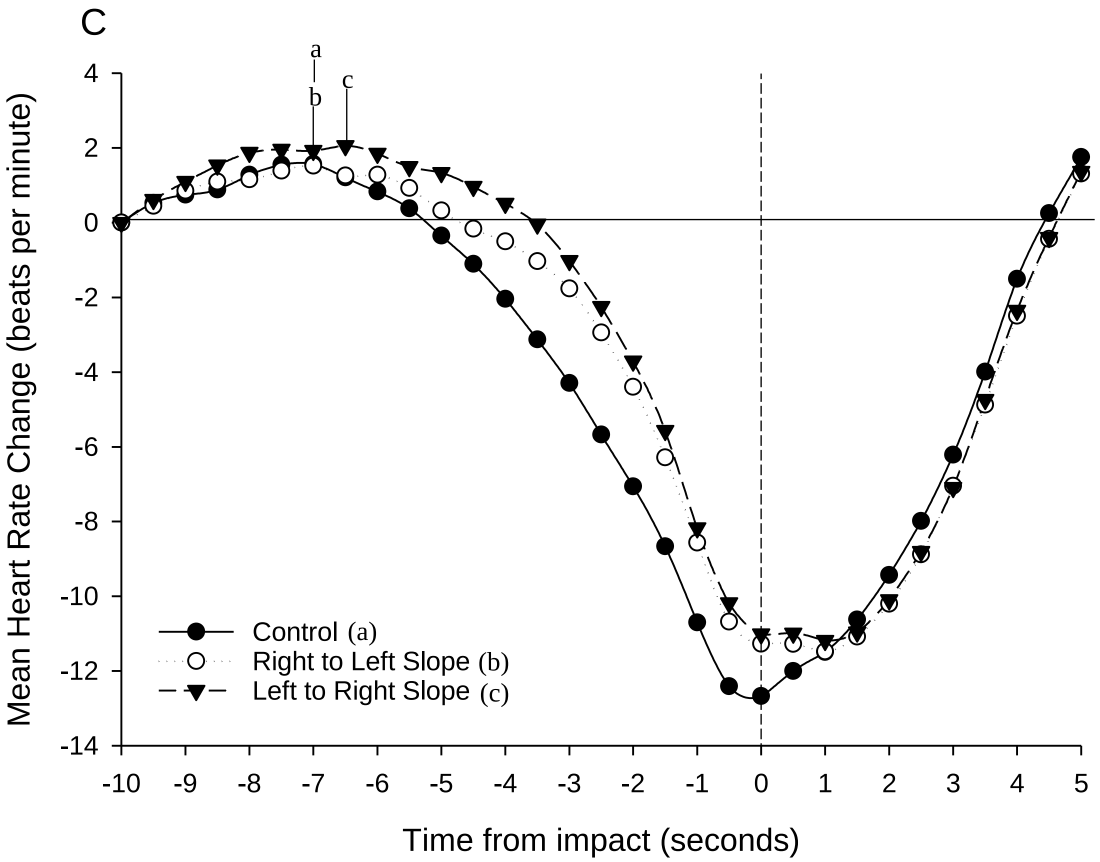


Figure 3.1: Mean heart rate (HR) change relative to 10 s before impact during a 15 s recording period for the control condition and the difficulty sub-theme conditions of (A) distance from hole, (B) diameter of the hole and (C) putting surface profile. $^{a, b, c}$ indicate highest HR recorded before impact with the ball in each condition, and therefore the point where deceleration began. The lowest recorded HR for all conditions coincided with impact with ball (0 s).

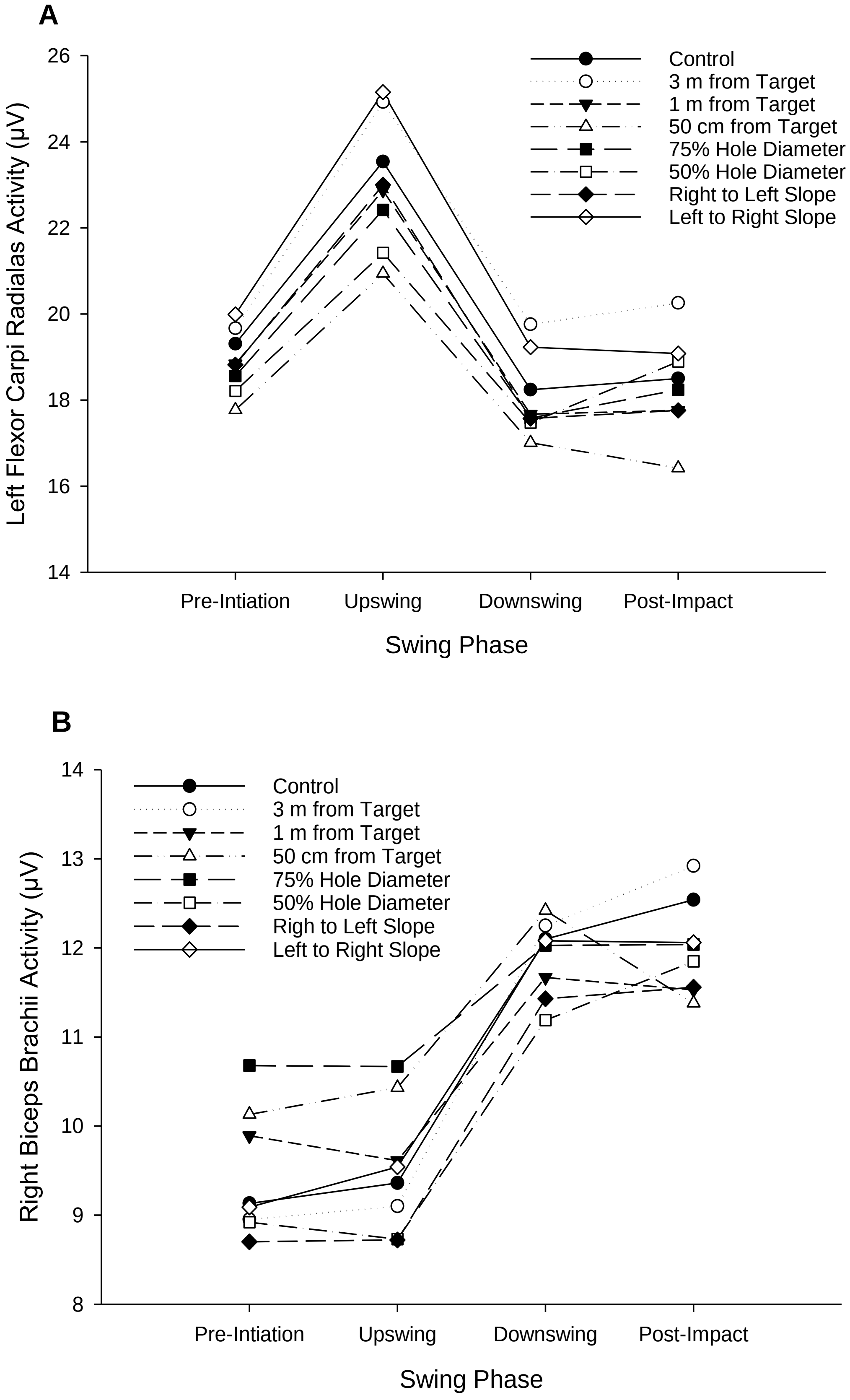


Figure 3.2: (A) Left flexor capri radialis muscle activity and (B) right biceps brachii muscle activity during each phase of the swing for task difficulty and control conditions.

	Task Difficulty Condition									
	Control	Distance from Target			Hole Diameter		Surface Profile			
		3 m	1 m	50 cm	50%	75%	Right-to-left Slope	Left-to-right Slope	*F(7,33)*	η^2
Measure (range of scores possible)	Mean (*SD*)									
Performance										
Mean Radial Error (cm)	9.30 (7.96)	28.14 ^{a} (18.72)	7.36 (6.54)	0.04 $^{a, b}$ (0.26)	17.55 $^{a, c}$ (12.10)	12.10 ^{a} (10.06)	12.65 (12.91)	24.62 $^{a, d}$ (16.33)	24.88***	.84
Number of Holed Putts (0-9)	6.55 (1.88)	3.78 ^{a} (1.98)	6.90 (1.89)	8.98 $^{a, b}$ (0.16)	3.73 $^{a, c}$ (2.24)	5.65 ^{a} (2.20)	6.28 (2.40)	5.13 $^{a, d}$ (2.13)	64.90***	.93
Psychological										
Perceived Task Difficulty (1-7)	2.68 (1.17)	4.76 ^{a} (1.38)	2.81 ^{b} (1.36)	1.62 $^{a, b}$ (0.86)	5.03 $^{a, c}$ (1.20)	4.19 ^{a} (1.45)	4.32 ^{a} (1.43)	4.51 ^{a} (1.51)	53.49***	.92
Effort (1-7)	4.93 (0.94)	5.06 (0.86)	4.65 $^{a, b}$ (1.07)	4.17 $^{a, b}$ (1.49)	5.15^{a} (0.93)	5.07 (1.00)	5.04 (1.02)	5.17 ^{a} (0.87)	4.86**	.51
Conscious Processing (1-7)	3.49 (0.75)	3.75 ^{a} (0.69)	3.51 ^{b} (0.70)	2.84 $^{a, b}$ (0.82)	3.66 $^{a, c}$ (0.67)	3.49 (0.77)	3.50 (0.76)	3.61 (0.72)	10.67***	.69
Perceived Pressure (1-7)	2.38 (1.34)	2.59 (1.44)	2.75 ^{a} (1.44)	2.09 ^{b} (1.44)	2.52 (1.47)	2.54 (1.45)	2.56 (1.48)	2.45 (1.34)	2.81*	.37
Physiological										
Heart Rate (bpm)	85.95 (12.50)	85.47 (12.74)	85.10 (12.40)	84.97 (12.39)	84.89 ^{a} (11.98)	84.84 (12.14)	83.89 ^{a} (12.18)	84.08 ^{a} (11.62)	3.72**	.44
SDNN (ms)	83.37 (2.25)	81.38 (1.86)	84.74 (2.28)	80.77 (1.87)	83.13 (2.13)	85.73 (2.32)	79.82 (1.92)	83.92 (2.09)	1.57	.25
r-MSSD (ms)	40.24 (18.88)	40.63 (20.31)	41.87 (19.75)	46.53 (27.97)	40.91 (19.96)	42.31 (19.15)	41.51 (17.73)	43.58 (18.46)	2.30	.33
Change in Heart Rate (bpm)	-14.25 (8.39)	-11.77 ^{a} (6.85)	-14.60 ^{b} (8.57)	-12.96 (7.26)	-12.38 ^{a} (7.43)	-13.45 (7.22)	-12.80 (6.32)	-13.07 (6.65)	3.00*	.39
Rate of Heart Rate Deceleration (bpm)	-122.10 (71.88)	-78.47 ^{a} (45.64)	-134.81 ^{b} (79.10)	-194.37 $^{a ,b}$ (108.97)	-92.89 $^{a, c}$ (55.69)	-115.25 (61.93)	-109.69 (54.17)	-120.67 (61.39	17.06***	.78
Heart Rate at Impact (bpm)	75.09 (12.65)	76.06 (11.92)	73.69 (10.30)	74.56 (11.48)	75.18 (11.96)	74.87 (11.57)	74.47 (11.50)	73.60 (11.22)	1.98	.30
Left Flexor Carpi Radialas EMG (μV)	10.58 (9.72)	10.43 (9.22)	10.35 (9.50)	10.31 (10.23)	10.12 (9.33)	10.29 (9.11)	10.48 (9.90)	10.98 (10.42)	1.47	.24
Right Biceps Brachii EMG (μV)	8.54 (5.62)	8.24 (5.84)	8.35 (5.71)	8.75 (5.79)	8.05 (5.26)	8.99 (7.16)	8.23 (5.56)	8.31 (5.63)	0.44	.09

Continued…

	Task Difficulty Condition									
	Control	Distance from Target			Hole Diameter		Surface Profile		*F(7,33)*	η^2
		3 m	1 m	50 cm	50%	75%	Right-to-left Slope	Left-to-right Slope		
Measure (range of scores possible)	Mean (*SD*)									
Kinematic										
X-axis acceleration (m.s^{-2})	0.50 (0.14)	0.62 ^{a} (0.18)	0.34 $^{a, b}$ (0.09)	0.28 $^{a, b}$ (0.07)	0.45 $^{a, c}$ (0.13)	0.48 ^{a} (0.14)	0.56 ^{a} (0.16)	0.58 $^{a, d}$ (0.17)	36.71***	.89
Z-axis acceleration (m.s^{-2})	3.22 (0.76)	3.65 ^{a} (0.75)	2.66 $^{a, b}$ (0.61)	2.34 $^{a, b}$ (0.53)	3.00 ^{a} (0.67)	3.07 ^{a} (0.71)	3.51 ^{a} (0.75)	3.50 ^{a} (0.71)	72.54***	.94
Y-axis acceleration (m.s $^{-2}$)	0.58 (0.49)	0.67 ^{a} (0.50)	0.47 $^{a, b}$ (0.36)	0.46 $^{a, b}$ (0.34)	0.57 (0.51)	0.59 (0.53)	0.61 (0.54)	0.66 $^{a, d}$ (0.58)	10.79***	.70
RMS Jerk (m.s^{-3})	3.18 (0.71)	3.60 ^{a} (0.73)	2.65 $^{a, b}$ (0.60)	2.35 $^{a, b}$ (0.54)	2.95 ^{a} (0.63)	3.03 ^{a} (0.67)	3.47 ^{a} (0.72)	3.46 ^{a} (0.69)	72.33***	.94
Smoothness	67.74 (12.56)	68.21 (10.30)	63.99 $^{a, b}$ (10.94)	61.53 $^{a, b}$ (10.54)	67.59 (11.82)	69.03 ^{c} (12.40)	65.46 ^{a} (10.95)	64.35 ^{a} (11.15)	7.21***	.61

Table 3.1: Mean *(SD)* of each measure for control and experimental conditions. ^{a} indicates significant difference from control condition, ^{b} indicates significant difference from the 3 m condition within the distance from target sub-theme, ^{c} indicates significant difference between the 75% hole diameter and 50% hole diameter conditions, and ^{d} indicates significant difference between the right-to-left and left-to-right conditions. ***$p < .001$, ** $p < .01$, * $p < .05$.

	Mean Radial Error		
	Heart Rate at Impact	Change in Heart Rate	Rate of Heart Rate Deceleration
ID		*r*	
1	-.13	.14	.43
2	-.43	.14	.45
3	-.28	-.15	.11
4	-.41	-.55	-.20
5	-.27	.13	.17
6	.29	.31	.61
7	-.26	-.09	.27
8	-.43	.27	.38
9	.64	.55	.79
10	-.55	.10	.24
11	-.17	.28	.33
12	-.29	-.22	-.08
13	.04	-.11	.33
14	-.05	.43	.55
15	.37	.27	.57
16	.49	.27	.61
17	.38	-.11	.55
18	.17	.85	.69
19	.29	.61	.66
20	.02	.01	.49
21	-.40	.34	.68
22	.11	-.32	-.05
23	-.04	.04	.40
24	.41	.46	.53
25	.10	-.15	.07
26	-.67	.36	.44
27	.64	.80	.85
28	.60	.60	.64
29	-.12	.08	.53
30	.11	.35	.48
31	.34	.25	.39
32	.95	.68	.94
33	.17	.16	.82
34	-.19	.28	.64
35	.25	.62	.80
36	.42	.14	.49
37	.48	.56	.57
38	.38	.04	.39
39	.18	.06	-.07
40	.13	-.53	-.13
Mean r	.11	.23	.48**
t(39)	1.46	3.69***	8.30***

Table 3.2: Correlation analysis for mean radial error with each cardiac measure associated with preparatory bradycardia across the control and seven experimental conditions for each participant. Within participants, mean radial error was correlated with the means of the 3 separate cardiac variables (8 performance x 8 cardiac) across conditions to create a Pearson’s correlation coefficient for each participant. *r* is presented in the transformed Fisher Z format, whilst Mean *r* is back transformed. ****p* < .001, ** *p* < .01

	Number of Holed Putts		
	Heart Rate at Impact	Change in Heart Rate	Rate of Heart Rate Deceleration
ID		*r*	
1	.08	-.24	-.56
2	.52	-.01	-.38
3	-.52	-.50	-.80
4	.24	.35	.07
5	.26	-.28	-.40
6	-.41	-.48	-.64
7	-.49	-.13	-.34
8	.63	-.48	-.77
9	-.68	-.56	-.84
10	.73	-.20	-.34
11	-.12	-.65	-.69
12	.44	.45	.30
13	-.60	-.40	-.74
14	.05	-.58	-.60
15	-.50	-.21	-.58
16	-.44	.02	-.74
17	-.09	.24	-.45
18	-.11	-.87	-.72
19	-.38	-.76	-.93
20	.00	-.09	-.44
21	.65	-.33	-.64
22	-.04	.35	.10
23	-.33	-.42	-.69
24	-.65	-.19	-.59
25	-.21	-.26	-.41
26	.53	-.16	-.42
27	-.72	-.75	-.84
28	-.42	-.59	-.71
29	-.03	.13	-.43
30	-.16	-.52	-.88
31	-.26	-.25	-.37
32	-.89	-.36	-.74
33	.13	-.22	-.82
34	.35	-.24	-.65
35	-.23	-.32	-.71
36	-.27	-.03	-.52
37	-.79	-.89	-.78
38	-.32	.20	-.35
39	-.18	.04	.18
40	-.02	.56	-.05
Mean r	-.16	-.28	-.58
t(39)	-1.95	-4.12***	-9.77***

Table 3.3: Correlation analysis for number of holed putts with each cardiac measure associated with preparatory bradycardia across the control and seven experimental conditions for each participant. Within participants, number of holed putts was correlated with the means of the 3 separate cardiac variables (8 performance x 8 cardiac) across conditions to create a Pearson’s correlation coefficient for each participant. *r* is presented in the transformed Fisher Z format, whilst Mean *r* is back transformed. ***$p < .001$

Discussion

Under the premise that increased task difficulty would require greater attentional processes, the present research aimed to identify differences in patterns of cardiac activity in experienced golfers during the seconds preceding a golf putt. The HR deceleration pattern was observed as expected in all conditions, with the magnitude of deceleration ranging from 10 to 14 bpm in the 10 s before impact with the ball. Post-impact acceleration was then present in the 6 s following impact, at which point HR returned to baseline levels. These observations are in line with previous work in golf putting (Boutcher & Zinsser, 1990; Cooke *et al.*, 2014; Neumann & Thomas, 2009, 2011). Whilst the magnitude of HR deceleration was found to be affected by condition, in contrast to the hypothesis, it was found to decrease in two of the more difficult conditions. Although a mirrored finding was observed in terms of HR deceleration increasing in the easier 1 m condition compared to control, no change in magnitude of bradycardia was seen in the easiest condition compared to control. Correlative analysis instead revealed the rate of HR deceleration to be the feature of cardiac activity most associated with changes in task difficulty. Taken together, the findings of this study indicate that HR at impact was not affected by task difficulty, and whilst the magnitude of heart rate was found to vary across conditions, HR deceleration was a better correlate of performance and could therefore be the best candidate for representing attentional processes implicated with performance. In essence, HR deceleration started sooner and took longer to reach the lowest level when task difficulty increased, but started later and decreased more rapidly in easier conditions compared to control.

In line with Lacey and Lacey's (1970, 1974, 1980) intake rejection hypothesis, these results suggest that external focus of attention is a feature of the preparatory phase of skilled motor performance in experienced golfers. The condition differences observed in the present study could be indicative of how athletes process external cues when a task is more difficult. For instance, perhaps a slower rate of HR deceleration represents participants requiring additional information and/or time to process environmental factors which facilitate successful task completion. In the 3 m from target condition for example, HR deceleration was 44 bpm slower than in the control condition. Putting from a greater distance may have meant participants adopted an external focus of attention earlier in their pre-performance routine, because they required longer to process external factors (e.g., ball start line, anticipated ball path, and/or distance the ball needs to travel). The rate of HR deceleration was also observed to be slower in the 50% hole diameter condition, another condition which was perceived to be more difficult and resulted in a decreased number of holed putts compared to control. Similar to these findings, Tremayne and Barry (2001) found HR deceleration began 3.5 s earlier when expert pistol shooters performed their best shots compared to their worst. In further support of the present discussion, the authors interpreted this earlier onset of HR deceleration as a more efficient narrowing of attentional focus and greater engagement with the task; a concept which is intuitively linked with task difficulty, i.e., engagement is likely to be greater as a function of task difficulty. Outside of sport, an increased duration of HR deceleration has also been linked to greater engagement in infants watching a television programme (Richards & Casey, 1991). In combination, the present findings suggest that a slower rate of HR deceleration may be indicative of attentional processes changing as a function of task difficulty.

In further support of this interpretation, the opposite was seen in the 50 cm condition, where the rate of HR deceleration increased by 72 bpm compared to control. This condition also produced a 99.8% success rate in terms of number of holed putts and was perceived by participants as easier than the control task. Linking the rate of HR deceleration to the intake-rejection hypothesis, the 50 cm condition may be representative of participants requiring a shorter preparation phase as they were able to process external cues more efficiently and/or easily. In combination with previous findings suggesting that the magnitude of HR deceleration increases as a function of expertise (Cooke *et al.,* 2014; Neumann & Thomas 2009, 2011), inconsistencies across conditions in terms of the observations related to the change in HR, may infer that the magnitude of HR deceleration can only be increased through greater skill acquisition, and cannot be manipulated by task difficulty. Instead, experienced athletes may be able to adapt the preparatory cardiac pattern in response to greater processing of environmental cues being necessary for successful task completion. In the present research, this is reflected by a slower rate of deceleration generally corresponding to more difficult tasks. Whilst this study provides evidence to suggest that performance may also be linked to changes in the rate of HR deceleration, further research is required to unequivocally identify whether the magnitude of HR deceleration or rate of HR deceleration is the best indicator of successful performance.

According to Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis, HR acceleration is a manifestation of internal focus of attention, and presumably, therefore, increased conscious processing. Although participants exhibited HR deceleration in all conditions, and thus, were most likely engaging in external focus of attention processes throughout this study, participants reported greater levels of conscious processing in both conditions where a slower rate of HR deceleration was observed (i.e., 3 m from target, 50% hole diameter). The fact that HR decelerated less in two out of three conditions where conscious processing reportedly increased, could indicate that internal attentional processes were more prevalent. The 1 m condition, which was the only condition where HR deceleration was greater, did not however produce a decrease in conscious processing.

These inconsistencies again suggest that the rate of deceleration may offer a stronger explanation for the relationship between conscious processing and the intake-rejection hypothesis. The slower rate of deceleration seen in conditions where conscious processing increased, may be indicative of participants engaging in both internal and external attentional cues. In a crude sense, physiologically this could mean HR deceleration takes longer to reach optimal levels, because the battle between attentional processes results in concurrent HR acceleration and deceleration. For instance, in the 3 m from target condition, participants will have needed to programme a movement that resulted in greater force, whilst a greater emphasis on face angle at impact (manipulated by wrist movements during the swing) would have been important in the 50% hole diameter condition to ensure a more accurate start line. Given the clear links to biomechanical processes, it is likely that participants would have been engaging in internal focus of attention regarding the way their body needed to move to produce a successful putting stroke in these conditions. However, external focus of attention was also likely to be a key determinant of success, as environmental cues would have been crucial for aim and direction of putting stroke. Moreover, in the ‘easiest’ condition (50 cm from target) where the rate of HR deceleration was quickest, conscious processing was lower than in the control condition. This further supports the influence of conscious processing on preparatory cardiac activity, as planning and programming tends to be more automatic in easier tasks (Landers *et al.,* 2005). Ultimately, the slower rate of deceleration observed as a function of task difficultly in the present study, could lend further support to preparatory cardiac deceleration being indicative of attentional processes in experienced golfers, as it may suggest greater engagement in internal attentional processes.

In recognition of the established relationship between gaze behaviours and preparatory cardiac activity (Moore *et al*., 2012), quiet eye theorising should also be considered as an explanation for the present findings. The slower rate of HR deceleration in the more difficult tasks may be a result of participants exhibiting a longer quiet eye duration (Vickers, 1996). The present findings are concurrent with this angle of visual activity research, which suggests that participants fixate their eyes, and presumably their attention, on a target for longer when the task is more difficult (Walters-Symons *et al*., 2018). Early quiet eye studies support this notion by suggesting that a longer quiet eye duration could be associated with an extended motor preparation period during which the parameters of the movement (e.g., direction and force) are programmed (Mann *et al*., 2011; Vickers, 1996). More recent studies have meanwhile all attributed a greater importance on post-movement quiet eye initiation period to performance success (Causer *et al*., 2017; Gallicchio *et al*., 2018; Gallicchio & Ring, 2020), as it may encourage a longer and smoother movement execution. This casts doubt over the explanation that a slower rate of HR deceleration is indicative of greater and/or longer motor programming processes during a preparatory quiet eye period in response to task difficulty. To help validate a relationship between gaze and cardiac activity in the seconds before and/or after skilled motor performance, future studies should measure distinct pre- and post-movement quiet eye periods relevant to phasic HR.

Previous data has suggested that the beneficial effects of HR deceleration as a result of external focus of attention may be influenced by increased anxiety (see Cottyn *et al*., 2008). Where the demands of the task outweigh ability, anxiety has been shown to increase (Eysenck & Calvo, 1992). Anxiety as defined by Spielberger (1989) often manifests as feelings of tension, apprehension and nervousness, unpleasant thoughts, or physiological changes. Perhaps the slower rate of HR deceleration seen during more difficult tasks in this study, is therefore indicative of participants having to attribute some attentional processes to filter out task-irrelevant cues, such as worrisome thoughts about not possessing the necessary skills to perform successfully. However, the fact that HR deceleration was exhibited in each condition, suggests that despite attentional processes being disrupted, participants remained able to focus externally in an attempt to achieve an optimal state of readiness; it just took longer for this state to be attained. In support of this perspective, Hassmén and Koivula (2001) found highly skilled golfers who displayed high levels of trait anxiety took longer to complete putts than participants with low trait anxiety. The conclusions of the current study are limited though, as time taken to complete putts was not measured. Nonetheless, the fact that tonic HR conversely decreased in three of the five more difficult conditions compared to control, casts doubt over this notion, as increased levels of anxiety are normally accompanied by an increase in HR (Åstrand *et al*., 2003). Furthermore, the demographic selected for this study should have possessed the necessary skills to hole putts in each condition. Considering professional golfers generally hole 70% of standard putts from 2 m (http://www.pgatour.com), participants exhibiting as success rate of 42% in the two most difficult tasks suggest adequate skill capability. In sum, although previous studies have shown a link between anxiety and HR deceleration, it is unlikely that the present findings regarding rate of HR deceleration are related to increased anxiety as a result of task difficulty.

Given the sensitivity of the cardiovascular system in response to physical changes, Obrist's (1968) theory of cardiac-somatic coupling and uncoupling may offer another explanation for the current findings. For example, Boutcher and Zinsser (1990) found that more experienced golfers took longer to address the ball and had longer pre-performance routines compared to beginner golfers.

Although the authors did not consider their findings from Obrist's (1968) perspective, this observed difference could account for the established expert novice variation in HR deceleration. The slower rate of HR deceleration in more difficult tasks found in the present study, may similarly reflect the hypothesis that HR deceleration is indicative of motor quieting. Postural control is attentionally demanding, and these demands increase with the complexity of the postural task being performed (Woollacott & Shumway-Cook, 2002). Therefore, motor quieting, and thus, HR deceleration may take longer in tasks requiring greater postural control. For example, the 3 m from target condition would have required greater stability to account for the increased Z-axis acceleration required to hit the ball further. Conversely, less attention would have been required to adopt a beneficial postural position for the physically less demanding 50 cm condition. Hence, participants did not need as long to achieve optimal motor quieting.

Postural changes (i.e., gravitational effects) are also strongly associated with the cardiovascular system. The rate of HR deceleration could have differed across conditions because of changes in pre-performance physical behaviours. For example, in the 3 m condition participants may have taken longer to adopt a bent over putting posture to ensure stability. The rate of HR deceleration may therefore have been slower because slower movements may have meant the cardiovascular changes associated with posture would have been more gradual. In contrast, as less motor planning and programming may have been required in the easier 50 cm condition, a faster rate of HR deceleration in this condition could reflect participants addressing the ball more quickly. Likewise, the acceleration observed immediately following impact with the ball in all conditions, could correspond with participants returning to a full standing posture. However, although postural stability has been linked to successful rifle shooting performance (Konttinen, *et al*., 1998), this feature of preparation for action appears less pertinent for golf putting accuracy (e.g., Babiloni *et al.,* 2008).

Moreover, EMG appears to have increased during the pre-initiation swing phase from tonic levels. This suggests that muscle activity may be greater during the preparatory phase of a putting stroke, and therefore, is not supportive of physical influences (i.e., Obrist, 1968). Furthermore, the fact that no changes in EMG were observed across conditions for the left flexor carpi radialas or right biceps brachii sites, suggest that if muscle activity is responsible for cardiac changes, then the implicated muscles activity is derived from other muscles not measured here. To help either eliminate or implicate physical processes in preparatory cardiac patterns, future work should analyse EMG recordings in smaller epochs relative to impact with the ball, and be mindful of physical behaviour's participants exhibit as part of pre- and post-performance routines when examining psychophysiological findings.

Similarly, HR deceleration could potentially be explained by respiratory influences on the cardiovascular system. Respiratory sinus arrythmia is a well-documented phenomenon which corresponds to HR slowing down during exhalation. Although previous research has shown that experienced golfers exhibit a diverse range of respiratory patterns in the seconds preceding a golf putt (Neumann & Thomas, 2009), participants may have changed their respiratory pattern in response to more difficult tasks. For instance, in the 3 m condition participants may have started their final pre-putt exhalation earlier in their pre-performance routines. Moreover, a dominant pattern of exhalation in the seconds preceding putting performance has been shown in elite golfing cohorts (Neumann & Thomas, 2009), suggesting that this may be a beneficial strategy. If this explanation is correct, then it may also account for the post-impact acceleration phase, where most skilled golfers may be inhaling following a pre-putt exhale and subsequent skill execution. This highlights another limitation of this study; no respiratory measures were recorded. To unequivocally link the rate of HR deceleration with attentional processes, future research should explore respiratory patterns concurrently with cardiac activity.

Conclusion

In conclusion, the present study confirms that the HR deceleration pattern seen in the seconds preceding skilled motor performance can be manipulated as a function of task difficulty. In contradiction to the hypothesis, the magnitude of HR deceleration did not consistently increase as a result of task difficulty evoking greater attentional processes. Instead, the most difficult tasks produced a slower rate of HR deceleration compared to control, whilst the easiest task resulted in a quicker rate of HR deceleration. The rate of HR deceleration was also found to be the strongest correlate of performance and could perhaps be indicative of attentional efficiency. These observations could be explained by attentional processes (Lacey & Lacey, 1970, 1974, 1980) or physiological reflexes (Obrist, 1968). Future studies should be mindful of methodological design to minimise limitations concerning pre-performance routines and physiological measures. Moreover, the present work should be expanded to explore this phenomenon in different demographics and different tasks, whilst analyses should focus on making links between cardiac activity and performance. With the disruption of attentional processes commonly implicated in the mechanisms of ‘choking under pressure’ (Eysenck & Calvo, 1992; Masters, 1992), HR deceleration should also be examined in pressurised scenarios. In combination, these results could ultimately pave the way for objectively optimising attentional processes, and thus performance.

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CHAPTER FOUR

Novice Performance in Response to a Dual Task, Increased Task Difficulty, and Greater Pressure; a Psychophysiological Approach to Exploring Attentional Processes

Abstract

Specific cardiac patterns prior to movement onset have been associated with attention. It has been established that expert performer's exhibit heart rate (HR) deceleration in the seconds prior to the execution of a target-based motor skills (Cooke *et al*., 2010; Cotterill & Collins, 2005; Neumann & Thomas, 2009). Although this heart rate slowing phenomenon is well documented and has been proposed as an objective measure of external focus of attention (Lacey and Lacey, 1970, 1974, 1980) the specific features of this deceleration profile have yet to be established. Under the premise that a dual task, task difficulty, and pressure all have the potential to disrupt attentional processes, the current study was designed to improve our understanding of this bradycardia, and furthermore determine its association with performance and attentional processes. 102 novice participants completed a series of dart throws under control and eight counterbalanced conditions. A series of repeated measures ANOVAs found condition to significantly affect performance, psychological state, and cardiac measures. The dual task, task difficulty and pressure affected performance, attentional processes, and phasic bradycardia pattern differently. Notably, HR acceleration was observed in the single trial pressure condition. In sum, the findings presented provide tentative evidence that preparatory bradycardia may be affected by a dual task and pressure, but not task difficulty. Furthermore, an increase in HR deceleration in the dual task paradigm strongly implicates this cardiac pattern as an objective measure of more effective external focus of attention (Lacey & Lacey, 1974).

Introduction

In fine motor control sports, such as darts, attentional processes are synonymous with performance outcome (Abernethy *et al*., 2007; Wulf, 2007). In particular, the disruption of attentional processes has been strongly implicated with athletes ‘choking’ under pressure (e.g., Baumeister, 1984, Masters, 1992). In essence, if attention is not effectively directed, or attentional demands exceed individual capabilities, performance dependant environmental information may be missed, and thus, performance may deteriorate (Wickens & McCarley, 2019). Two theories based on increased self-focus have been offered to explain the mechanistic properties of choking. Firstly, Baumeister (1984) suggested that performers attempt to consciously control skill under pressure as result of increased self-focus, but that “*consciousness does not contain the knowledge of these skills, so it ironically reduces the reliability and success of performance*”. Secondly, Masters (1992) similarly argued that choking is prevalent when individuals reinvest explicit knowledge or adopt great conscious processing to achieve successful performance under pressure. Together with Baddeley’s (1986) tripartite model of working memory processing efficiency theory directly links pressure, anxiety, and effort (Eysenck & Calvo, 1992), and represents a third proposed model of choking. Anxiety almost always accompanies pressure in sport (Mullen *et al*., 2005) and mainly affects the central executive (capacity control centre) of working memory (Baddeley, 1986), which is responsible for self-regulatory functions and active processing. Processing efficiency theory assumes that once anxiety has consumed auxiliary capacity beyond an ability to retain on-task attention, performance is likely to deteriorate. Ultimately, these theories in combination imply that pressurised scenarios heighten self-focus and effort, resulting in attentional processes being disrupted, which will most likely have detrimental effects on performance.

External focus of attention has been attributed to improved performance under control and pressurised conditions (Hardy *et al*., 1996; Lohse *et al*., 2010; Maddox *et al*., 1999; Wulf *et al*., 1999, 2003; Wulf & Su, 2007; Wulf & Weigelt, 1997). In a learning environment, it has been consistently demonstrated (Lohse *et al*., 2010; Maddox *et al*., 1999; Wulf *et al*., 1999) that instructing participants to focus their attention on how their movements affect an external source (e.g., equipment such as a dart, golf club, or balance board) is more effective for performance than focusing on the way their body moves to influence the external source (e.g., arm or leg motor control). Moreover, external focus instructions whilst learning new skills have proven more advantageous in retention and transfer tests (Wulf *et al*., 1999), for example when participants are asked to perform the newly learned skill under pressure. Mechanistically, Lohse *et al*., (2010) linked external focus of attention to improved neuro-muscular efficiency, with less muscle activation coinciding with improved movement outcome. In further support of these findings, previous studies have also identified that greater proximal focus points have a more positive impact on performance (McNevin *et al.*, 2003). With a mounting body of research in favour of external focus of attention facilitating accelerated learning and more robust performance, Wulf and colleagues have conceptualised the constrained action hypothesis (Wulf *et al*., 2001). This model surmises that whilst internal focus of attention encourages conscious control, and thus, inhibits automatic control mechanisms, external focus of attention enables automatic control mechanisms to run without interference. Practically, Masters *et al.'s* (2005) movement specific reinvestment scale suggests that individuals are more likely to have exhibited conscious processing if they rank items such as "*I am aware of the way my body works when I am carrying out a movement*" highly. Taken together, the evidence for external focus of attention facilitating better performance appears to be synergistic with self-focus theories of choking.

Whilst several self-report measures, such as Masters *et al*.'s (2005) movement specific reinvestment scale, have been developed to monitor focus of attention, an objective tool for measuring attentional processes remains elusive. Psychophysiological methods provide a concurrent measure of performance-related processes, and therefore offer researchers the means to objectively investigate attentional processes related to skilled motor performance under pressure (Abernethy *et al*., 2007; Collins 2002). For instance, a short-term phasic pattern of heart rate (HR) deceleration is thought to be indicative of external focus of attention (Lacey & Lacey, 1970, 1974, 1980) in the seconds preceding skilled motor tasks (Hatfield *et al*., 1987; Neumann & Thomas, 2009; Tremayne & Barry, 2001).

Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis suggests that bradycardia in the seconds before skilled motor task execution, increases flow of environmental information to the brain by reducing blood pressure, and thus, unloads the baroreceptors (Brunia, 1993). In contrast, environmental cues may not be as impactful when HR acceleration is present, as this cardiac pattern is believed to reduce the cortical response to external stimuli by inducing promotion of the bulbar restraint upon the reticular formation (Hatfield *et al*., 1987). Common interpretations of this phenomenon originate from historic reaction time paradigm studies by Lacey & Lacey (1970), where HR deceleration, beginning 3-4 beats before movement onset, was noted in the time between anticipatory and action commands.

More recent applied sports performance studies (Cotterill & Collins, 2005; Neumann & Thomas, 2009) have confirmed preparation for action HR deceleration in expert and novice cohorts. The magnitude of HR deceleration has been shown to vary as a function of expertise, with elite, experienced, and novice golfers having been found to exhibit HR deceleration of 12, 10, and 2 beats per min (bpm) respectively during the 6 s before they putt (Neumann & Thomas, 2009). In terms of how this preparatory cardiac pattern relates to attentional process, a difference between participants of varying expertise is consistent with learning paradigms, where expert performers will most likely have a greater focus of external attention as movement planning and programming is more automatic (Fitts & Posner, 1967; Shiffrin & Schneider, 1977). In comparison, novice performers will generally require a greater level of internal attentional processes to successfully execute correct motor control, as conscious processing is a characteristic of the declarative stage of learning. Combined, these studies provide tentative support for the preparatory bradycardia reflecting attentional processes. More specifically, HR deceleration in the seconds before skilled motor performance, may be indicative of individuals directing their attention towards external factors in order to inform automatic planning and programming phases of pre-performance routines.

However, whilst in agreement with Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis that HR deceleration is a preparatory characteristic of skilled motor performance, Obrist's

(1968) cardiac-somatic coupling and uncoupling theory disputes the underlying mechanisms of this cardiac pattern. Instead of baroreceptor unloading increasing environmental intake, this model suggests reduced muscle and metabolic activity are the causative factors of bradycardia in the seconds preceding skilled motor performance. In support of this notion, although Neumann and Thomas (2011) found HR deceleration to be greater as a function of expertise, attentional focus instructions only had an effect on tonic cardiac activity and not phasic changes prior to participants executing a golf putt. Similarly, Salazar *et al.*, (1990) attributed a null finding for pre-performance HR deceleration in an archery task to physical strain associated with holding a fully drawn bow weighing the equivalent of 14-22 kg. These contradictory positions concerning HR deceleration being indicative of external focus of attention, suggest that further research is warranted to fully understand this psychophysiological relationship.

Whilst studies have begun to disentangle preparatory bradycardia in relation to attentional processes (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009), it is unclear how pressure may affect HR deceleration and its relationship with external focus of attention. The pressure to perform well can stem from *'any factor or combination of factors that increases the importance of performing well on a particular occasion'* (Baumeister, 1984). Experimentally, pressure can be induced by manipulating the task, the performer, and/or the environment. Previous research has shown that external focus of attention and the potential beneficial effects of HR deceleration may be influenced by increased anxiety (see Cottyn *et al*., 2008). Anxiety, as defined by Spielberger (1989), often manifests as feelings of tension, apprehension and nervousness, unpleasant thoughts, or physiological changes such as an increase in HR (Åstrand *et al*., 2003), and where the demands of the task outweigh skill, anxiety has been shown to increase (Eysenck & Calvo, 1992). High-pressure situations often evoke anxiety (Staal, 2004), and in studies investigating skilled motor tasks (i.e., movements involving low physical exertion), an elevation in HR is generally considered as an objective measure of pressure (Cooke *et al*., 2010; Oudejans & Pijpers 2009, 2010; Stoker *et al*., 2019). For instance, increased task difficulty has been shown to induce pressure by manipulating task related factors, such as target size or distance from target (Stoker *et al*., 2017, 2019). Carroll *et al*., (1986) found a substantial main effect of difficulty level on HR, whilst Stoker *et al*., (2017) observed no effect of task difficulty on HR unless a consequence for poor performance was present. Similarly, anxiety and effort have increasingly been explored objectively through HR variability. Often assessed in low (0.02-0.06 Hz), mid (0.07-0.14 Hz), and high (0.15-0.50 Hz) frequency bands (Mulder, 1992), changes are influenced by the anxiety sensitive sympathetic and/or parasympathetic systems. For example, Cooke *et al*., (2010) showed an increase in the mid-band frequency correlate linked to mental effort (Carrasco *et al*., 2001; Mulder, 1992) SDNN (the standard deviation between R-wave intervals), when participants were subjected to high levels of pressure. Mechanistically, processing efficiency theory suggests that when tasks are difficult, worrisome thoughts about performing well will impose demands on working memory capacity mainly via the central executive. Therefore, anxiety can cause performance detriments when tasks are more difficult because greater demands are made on the resources of working memory. Furthermore, according to the elements of processing efficiency theory which concern performance effectiveness, greater expenditure of effort as a result of task difficultly, is associated with the allocation of additional processing resources. Stimulated by task difficulty, it may be that in trying harder, anxiety causes individuals to shift from automaticity to conscious motor control (Eysenck & Calvo, 1992). In addition, planning and programming tends to be more automatic in easier tasks (Landers *et al.*, 2005), and the benefits of external attentional focus seem to increase with greater task complexity (see Wulf, 2013). As such, the literature suggests that manipulation of task difficulty may evoke changes in attentional processes as a result of greater anxiety and/or effort. The coincidental disruption of HR deceleration in response to more difficult tasks could therefore add further support in favour of the intake-rejection hypothesis.

The introduction of consequences (e.g., punishment, reward, and evaluation) is another popular method of applying pressure in a laboratory setting (Bell *et al*., 2013; Driskell *et al*., 2014; Oudejans & Pijpers , 2009, 2010; Stoker *et al*., 2017, 2019). For example, Bell *et al.*, (2013) used the threat of having to clean a changing room post-training as a negative consequence, whilst Stoker *et al*.,

(2019) staged a media conference where poor performing participants had their performance scrutinised. In contrast, performance-contingent monetary incentives are regularly used to induce rewards-based consequences (Belilock & Carr, 2001; Masters, 1992, Oudejans & Pijpers, 2009). In terms of consequences/rewards associated with evaluation, Driskell *et al*., (2014) found that pressure increased in response to peer and/or coach evaluation, whilst Mesgano *et al*., (2011) reported increased pressure regardless of whether the evaluation was in person (i.e., audience) or remote (i.e., video recording to be assessed later by a figure of importance). Themes of evaluation are also frequently linked to competition. Competition is inherently threatening because it can induce both internal (e.g., over arousal, low self-efficacy) and external (e.g., expectations of teammates, audience, or coach) evaluations of competence (Martens, 1977). As defined by Baumeister and Showers (1986), "*Explicit competition occurs when subjects are clearly informed that their performance will be compared with the performance of others…Implicit competition arises when subjects will tend to compare their performances with those of coactors even though no explicit competitive arrangement is made*". Assuming that the performer desires to outperform other performers, pressure can occur in either competitive scenario. Whilst controversy remains regarding whether competition inhibits or enhances performance, and thus, induces 'choking' under pressure, competition promotes higher performance of motor skills than individualistic scenarios (Stanne *et al.*, 1999). Generally, the anxiety one feels prior to competition is recognised to be greater in individual than team sports (Martin & Hall, 1997). However, when faced with a scenario that will directly affect team-mates, Baumeister (1997) suggested that ego-threat may cause athletes to perform poorly under pressure. Empirically, Williams *et al*., (2002) found that table tennis performance was impaired by pressure in response to competition.

Where performance declines under pressure, researchers regularly cite self-focus theories of choking as a potential mechanism (Baumeister, 1984; Masters, 1992). In competitive scenarios for example, self-evaluation as a result of performance-contingent consequences is likely to induce self-focus. In essence, consciousness attempts to monitor motor control, programming, and planning to ensure correctness. However, because of the automaticity associated with expertise (Fitts & Posner, 1967; Shiffrin & Schneider, 1977), consciousness does not contain the knowledge of these skills. Ironically, this reduces the reliability of successful performance, and thus, choking can occur (Baumeister, 1984). In support of these theories, Gray (2004) suggested that a performer's knowledge about his or her movement execution (when asked to make a judgment after the movement is completed) is more accurate under pressure, i.e., internal focus of attention is greater in pressurised scenarios. This implies that under pressure (where the desire to succeed is arguable at its greatest, Beilock & Carr, 2001) individuals may become more consciously aware of the importance of executing a motor skill correctly. Hence, if HR deceleration is indicative of external focus of attention, it would be reasonable to expect this cardiac pattern to be affected by pressure. Whilst the literature supports the notion that tonic HR increases as a result of pressure (Åstrand *et al*., 2003; Cooke *et al*., 2010, 2014; Oudejans & Pijpers 2009, 2010; Stoker *et al*., 2019) and competition (Veldhuijzen van Zanten *et al.*, 2002), it remains unclear how pressure might affect the preparatory HR deceleration pattern seen in expert and novice skilled motor performance.

Dual task manipulations, whilst not often employed as direct means for inducing pressure, have also been used extensively in attention research. The use of secondary tasks in reinvestment (Masters, 1992) studies provides a resource-limiting method for placing demands on short-term memory capacity, so that the accumulation of explicit skill knowledge is reduced to virtually nil. Master's (1992) conscious processing model suggests that choking under pressure occurs because performers attempt to apply explicit rules to control movement. Extended by Jackson *et al*., (2006), it is proposed that this explicit monitoring may disrupt motor control and that additional disruption may occur when performers feel the need to consciously control and monitor skilled movements. Like Baumeister's (1984) model of reinvestment, theoretically, conscious processing is also reflective of the stages of skill acquisition (e.g., Fitts & Posner, 1967), where learning begins with declarative, explicit encoding of knowledge which normally results in slow, erratic, and conscious performance. As expertise progresses, skill becomes more automatic and non-conscious (Anderson, 1982). In expert performance, therefore, refocusing attention on motor control and monitoring as a result of increased self-focus, can cause performance quality to decline. Experimentally, although not all work has been fully supportive (e.g., Gucciardi & Dimmock, 2008; Mullen & Hardy, 2000), most studies which have encouraged conscious monitoring and control of movement, have observed a drop in performance. Beilock *et al*., (2002) concluded that skill-focus instructions caused a decline in performance compared to when participants were asked to complete a secondary task in golf putting and football dribbling, whilst Gray (2004) found that expert baseball batters performed worse when they focused on their movements rather than a secondary task. Similarly, Jackson *et al*., (2006) suggested that these findings were compounded by pressure. These studies demonstrate that a secondary task may prevent performers having sufficient working memory to engage in explicit processes, thus, protecting against the potential performance harming effects of conscious processing. Dual task methodology may therefore help researchers to further understand the relationship between attentional processing and preparatory HR deceleration.

With attentional processes strongly implicated in theories of choking under pressure, exploring how HR deceleration is affected by different types of pressure would appear a logical progression of research, and may provide the means to ultimately validate the relationship between preparatory bradycardia and external focus of attention. Under the premise that pressure, task difficulty, and a secondary task may affect attentional processes, the present study used a within-participant design to further explore HR deceleration in the seconds before skilled motor performance. From the literature reviewed above, it could be inferred that different pressures may provoke different psychophysiological responses. Therefore, in contrast to Baumeister’s (1984) popular study of pressure, a variety of isolated pressures, task difficulty manipulations, and a secondary task scenario were employed in the present study to help further explore the notion that not all pressures are equal and/or additive. Using the rationale that external focus of attention is beneficial for successful performance, and that HR deceleration in the seconds preceding skilled motor task is indicative of external focus of attention, it was hypothesised that HR deceleration would be reduced in conditions where performance worsened i.e., under pressure and in more difficult tasks. Whilst internal focus of attention was expected to increase in these conditions, in the secondary task condition it was expected to remain the same as control. Performance was meanwhile anticipated to decrease as a function of task difficulty and in conditions where pressure reached a level that would leave participants susceptible to choking.

Method

Participants

Novice (*M* times played socially in the last year = 6.21, *SD* = 30.14) male (n = 54) and female (n = 48) sport and exercise science students (*M* age = 19.28 years, *SD* = 0.67) were recruited as participants for this study. The protocol was approved by the local research ethics committee and all participants provided informed consent.

Task

Participants performed a dart throwing task. Previous research has used similar tasks to explore preparation for action paradigms (Lohse *et al*., 2010). Accurate planning and movement programming were integral to successful performance in this task, meaning that conscious processing and external focus of attention would have been predominant cognitive processes during the seconds before execution.

Performance Measures

Performance outcome was determined using a radial paper target pinned to a large cork board. Eight concentric circles (diameter increased in increments of 3.5 cm) provided participants with a score for each dart throw (0-8 points). Similar to a traditional dart board, the highest point tariff was awarded for hitting the centre circle. Contact between the dart and target board was registered by an impact sensor (Piezo Vibration Sensor, Measurement Specialties Inc, USA) attached to the cork backing board.

Psychological Measures

Pressure and effort. 5-item effort/interest and pressure/tension subscales of the Intrinsic Motivation Inventory (Ryan, 1982) were used to measure effort and pressure. These measures were employed to determine participant engagement and whether greater effort was associated with increased task difficulty and/or pressure tasks, whilst feelings of pressure have been associated with task difficulty (Carroll *et al*., 1986) and competition (Veldhuijzen van Zanten *et al*., 2002). Participants were asked to rate items like "*I tried very hard to do well*" for the effort subscale, and "*I felt pressured*" for the pressure subscale using a 7-point Likert scale anchored by 1 "*not at all*" and 7 "*very true*". The internal consistency of the effort and pressure subscales were respectively good (α = .31 to .73) and very good (α = .91 to .97) across conditions.

Attentional Processes. To explore the relationship between cardiac deceleration and attentional processes (Lacey & Lacey, 1970, 1974, 1980), a focus of attention pie chart (Appendix 1A) was employed to gauge where participants were focusing their attention in the seconds before movement onset. Participants were asked to split an unmarked circle into four segments to indicate how much they focused on different elements prior to movement onset; Internal task-related (e.g., posture, joint position, grip tension), external task-related (e.g., the dart, the target), internal task-unrelated (e.g., breathing, hunger, body temperature), and external task-unrelated (e.g., surroundings, noise, the experimenter). The pie chart was visually scored using the area of each segment to determine a percentage of the circles total area. Taken together, these four measures provided an insight into the cognitive processes exhibited in the seconds prior to throwing a dart.

Physiological Measures

Cardiac. To explore cardiac variables in the seconds before dart throwing, an electrocardiogram was recorded using three silver/silver chloride spot electrodes (Cleartrace, ConMed, Utica, NY) in a modified chest configuration. The signal was amplified (Delsys® Bagnoli-4 system, Boston, MA), filtered (1-100 Hz), and digitalized at 2500 Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK) using Spike2 software (Cambridge Electronic Designs). Although R-wave peaks were automatically identified by an interactive program, visual inspection and manual movement of scored points ensured correct scoring of the analog electrocardiographic signals. R-R interval analysis confirmed tonic HR and two-domain indices of HR variability (SDNN; standard deviation of R-wave to R-wave intervals, and rMSSD; root mean square of successive R-R intervals). Whilst gold standard HR variability recording is determined over long (24 hr) periods of time, researchers have proposed ultra-short-term recordings can be empirically relevant (Salahuddin *et al*., 2007). In short-term low-physically demanding recordings, parasympathetic mediated respiratory sinus arrythmia is the main contributor of variance for SDNN, whilst rMSSD is more reflective of vagally mediated changes concerning beat-to-beat HR variance (Shaffer & Ginsberg, 2017).

HR was also calculated for each 0.5 s epoch from 10 s before the dart hit the target board, to 5 s post-impact, which enabled a more specific investigation of the previously established cardiac deceleration phenomenon (Neumnan & Thomas, 2009). Depending on condition, HR at 2.5 s to 2 s before impact generally corresponded with the lowest point of the HR deceleration curve. Change in HR reflected magnitude of HR deceleration and was calculated using pairwise comparison (least significant difference) in each condition to identify the highest and lowest pre-impact HR. The highest HR was deemed to be the point where deceleration began, whilst the lowest point signified the end of preparatory HR deceleration. As such, the change in HR measure reflected the difference between the highest and lowest pre-impact HR in each condition. Rate of HR deceleration similarly used the high and low point of the HR deceleration profile (this difference was then divided by the time between corresponding epochs and converted to mins to reflect the HR unit bpm) and provided a description of the gradient of the HR deceleration curve. These variables in combination indicated how quickly and to what extent HR decelerated in the seconds immediately before skill execution.

Conditions

Control. Participants were required to throw nine standard darts 2 m to a 28 cm diameter concentric circle target (each scoring band measured 3.5 cm across), meaning participants could score 0-8 points for each dart throw. A distance of 2 m was chosen, because this is just under the standardised distance used in darts and was therefore deemed appropriate for novice participants. To allow adequate time for HR to return to normal between throws, participants were prompted via a computer programme when they could throw subsequent darts (10 s after previous dart impact). It was made clear that participants should not use this prompt as a reaction to perform, but instead should throw each dart in their own time having received the prompt. As performance was recorded by the experimenter following every three darts, participants had a further rest period twice during the condition (approximately 1 min).

Dual Task. Participants threw darts under control conditions whilst performing an additional mental task. Keeping in time with a loud metronome set at 60 bpm, participants were instructed to say random letters out loud in non-alphabetical order without repeating the same letter consecutively or using vowels. The addition of a mentally demanding task was designed to prevent participants employing the same level of attentional resources on dart throwing performance (i.e., planning and movement control), as attentional processes would have been consumed by the completion of the non-relevant mental task (see Masters, 1992). Thus, providing a transparent method of limiting short-term memory capacity so that explicit processes would be unachievable compared to control.

Reduced and Increased Distance. Participants performed under the same conditions as control, except all dart throws were taken from a closer distance of 1.5 m away from the target in the reduced distance condition, and a further distance of 2.5 m away from the target in the increased distance condition. These conditions were designed to manipulate task difficulty by increasing (increased distance) and decreasing (reduced distance) difficulty. Biomechanically, distance affects task difficulty by affecting the margin for error (i.e., shorter distances will allow for greater margin of error in dart throwing). Previous studies have validated an association between task difficulty and psychophysiological processes, with more difficult tasks associated with pressure and increased tonic HR (Carroll *et al*., 1986).

Reduced Target. Participants threw darts under the same conditions as control, but the target size was decreased by approximately 30%. The overall diameter was reduced from 28 cm to 20 cm, with the concentric circles changing from 3.5 cm to 2.5 cm scoring bands. Similar to the increased distance condition, the introduction of a reduced target size was designed to increase task difficulty.

Leader board. Control conditions were replicated, but participants were told their total score during this condition would count towards an experiment leader board displayed in the laboratory. The first placed participant at the end of the experiment would receive a £50 Amazon voucher. This condition was designed to elicit pressure through a performance-contingent reward, competition, and social evaluations; all strong themes of pressure research (Baumeister & Showers, 1986; Cooke *et al*., 2010, Mesgano *et al*., 2011).

Team Competition. Participants performed under the same conditions as control, whilst paired up with another participant to form a team. Pairings were dictated by scores recorded during the familiarisation stage of the experiment to ensure fair competition. Two teams performed simultaneously in a head-to-head competition, where the combined total score of each two-person team would determine a winner. Participants in the winning team were awarded a small chocolate bar as a prize. The potential internal and external evaluation of athletic competence makes competition inherently threatening, and thus, can elicit pressure induced choking (Martens, 1977). This task encompasses both individual and team elements, meaning pressure in this condition could stem from team, self, or competitor expectations, and a fear or failure (Adegbesan, 2007).

Individual Competition. Participants threw darts under control conditions whilst competing against another participant. Opponents were determined by scores recorded in the familiarisation stage of the experiment to ensure fair competition. The participant with the highest total score was rewarded with a large chocolate bar. An isolated condition for individual competition was important to include in the present study because anxiety has been shown to be greater in individual than team sports (Martin & Hall, 1997), and as anxiety almost always accompanies pressure in sport (Mullen *et al*., 2005), pressure could be greatest in this competition condition.

Winner. Participants performed under the same conditions as control, except they only threw one dart rather than nine. The experimenter informed all lab participants that they would be competing against each other in a ‘winner takes it all’ scenario. The participant who threw the highest scoring dart during this condition would be awarded a £5 Amazon voucher. Whilst scientific research often requires multiple trial protocols to amass adequate data for meaningful data analyses, ecologically, successful sport performance (particular involving skilled motor tasks) can often be dependent on one shot, one movement, or one moment in a game. This condition was employed to explore whether differences could be detected in a single trial scenario. It is also likely that with performance outcome dependent entirely on one dart throw, participants would experience greater pressure because the factors inducing pressure would be intensified.

Procedure

To avoid potential influences on cardiovascular activity, participants were asked to avoid caffeine consumption during the 4 h’s before their laboratory session. The experimental protocol was completed in groups of six, with opaque screens separating participants. Upon entering the laboratory, skin sites were exfoliated and cleaned ready for attachment of electrocardiogram electrodes. Secure attachment, and thus, good quality signal output was achieved by employing specialist electrode interfaces and medical tape. Participants completed nine dart throws under the same conditions as control to familiarise themselves with the equipment. Although unbeknown to the participants, performance was recorded during this familiarisation phase to help inform the creation of competitive pairings later in the experiment. A Latin square (Williams, 1949) was used to counterbalance the order for completing all conditions, including control, which complemented a within-participant design. No instructions or suggestions were given prior to, or during the experiment regarding dart throwing technique. Participants were informed repeatedly throughout the experiment to complete darts at their own pace once the computer prompt was displayed. The instructions for each condition were administered by the experimenter using a script. To help ensure consistency and eliminate any potential cardiac reactions to postural changes caused by participants moving around the lab to collect the darts themselves, darts were scored, removed from the target, and returned to participants at the throw line by the experimenter. Whilst computer programme prompts and score recording helped ensure rest between throws, participants were also asked to complete a post-condition self-report questionnaire, which provided a rest period of around 3 mins between conditions.

Statistical Analysis

Condition specific effects were explored using the multivariate solution from separate 9 condition repeated measures analyses of variance (ANOVAs). Follow up pairwise comparisons (least significant difference) were employed to further examine how performance, psychological, physiological and kinematic measures changed in each condition compared to control. Significant differences were deemed to exist if comparative values were outside the 95% confidence interval. As well as separate 9 condition repeated measures ANOVAs for the different HR indices, HR was also subjected to a 9 condition x 31 epoch (i.e. -10 s, -9.5 s … to +4.5 s, +5 s) repeated measures ANOVA (Figure 4.1). The risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVAs was minimised by reporting significant effects using the multivariate method. (Vasey & Thayer, 1987). Partial eta-squared was reported as a measure of effect size, with values of .02, .12 and .26 indicating relatively small, medium and large effect sizes respectively (Cohen, 1992).

Results

Effects of Pressure, Task Difficulty, and a Dual Task Paradigm on Performance

The separate 9 condition repeated measures ANOVAs confirmed a main effect for pressure on dart throwing scores (Table 4.1, top). Subsequent pairwise comparisons revealed that compared to control, performance improved by 11% in both the leader board and team competition and was 45% and 16% better in the reduced distance and individual competition conditions respectively. Conversely, performance was worse in the increased distance and reduced target conditions, where 40% and 20% reductions in average score were observed, respectively.

Effects of Pressure, Task Difficulty, and a Dual Task Paradigm on Psychological Measures

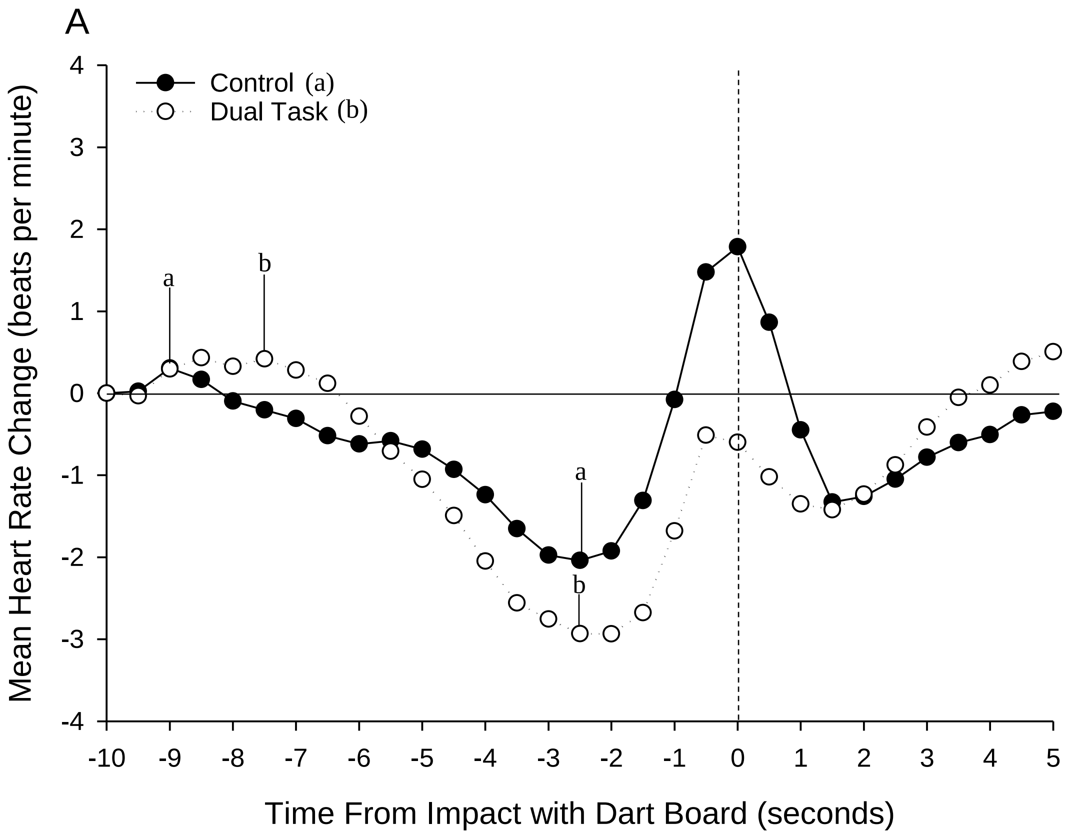
The separate 9 condition repeated measures ANOVAs showed main effects for condition on all psychological measures, except internal task-unrelated focus of attention (Table 4.1, middle). Pairwise comparisons revealed that participants exhibited greater effort in the reduced target, leader board, team competition, individual competition and winner conditions compared to control. Similarly, pressure increased in the increased distance, dual task, leader board, team competition, individual competition and winner conditions compared to control. Conversely, in comparison to control participants reported feeling less pressure in the reduced distance condition. In terms of the focus of attention pie chart, follow up pairwise comparisons showed that participants focused their attention more on internal task-related elements in the reduced distance and increased distance conditions compared to control. Contrastingly, attentional focus on internal task-related factors decreased in the dual-task condition. External task-related focus of attention decreased in the dual task, whilst external task-unrelated attentional focus was found to increase in the dual task condition compared to control. The percentage participants reported focusing on external task-unrelated components decreased in the leader board condition.

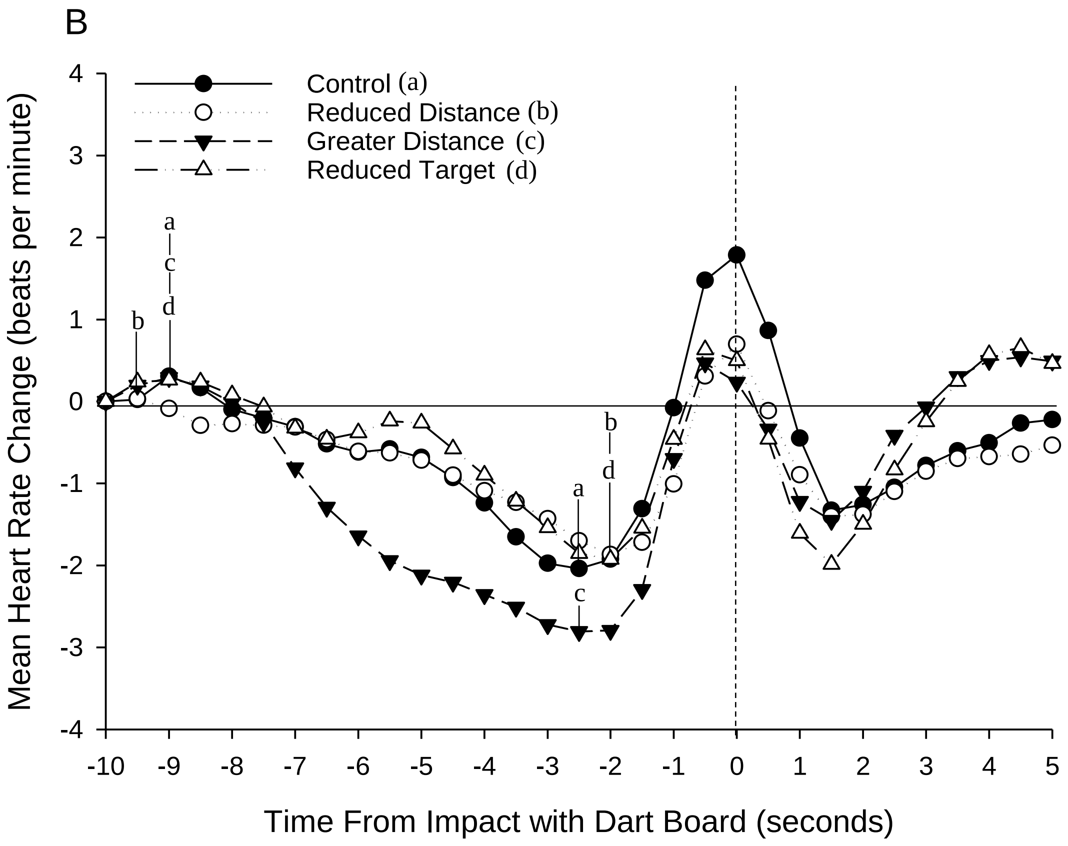
Effects of Pressure, Task Difficulty, and a Dual Task Paradigm on Physiological Measures

A HR deceleration profile in the seconds before movement onset was confirmed by a repeated measures 9 condition x 31 epoch ANOVA (Figure 4.1). Both condition, $F(8,94) = 14.22$, $p < .001$, $\eta^2 = .55$, and epoch, $F(30,72) = 9.88$, $p < .001$, $\eta^2 = .81$, effects were observed. Separate repeated measures 9 condition ANOVAs revealed main condition effects for all physiological measures (Table 4.1, bottom). Post-hoc pairwise comparison analysis showed that HR decreased in the reduced distance, increased distance, reduced target, and team competition conditions compared to control. Conversely, HR rose in the winner condition. In terms of HR variability, SDNN, was lower in the increased distance, dual task, reduced target, team competition and winner conditions compared to control. Similarly, rMSSD was lower in the dual task, leader board, team competition, individual competition and winner conditions compared to control. Participants exhibited a faster HR deceleration in the dual task condition compared to control. Whilst the cardiac measures aimed at exploring features of the HR deceleration pattern did not differ in the winner condition, figure 4.1 indicates that pre-movement HR acceleration began earlier in this condition compared to control. With the lowest HR being recorded in all other conditions within 0.5 s of the epoch where pre-movement HR was lowest in the control condition, this observation stands out. Computing change in HR ($M = 0.59$, $SD = 10.46$) and the rate of HR deceleration ($M = 10.18$, $SD = 179.34$) to represent this pre-movement HR acceleration phase, confirmed HR increased between -6 s and -2.5 s. In contrast to all other conditions, HR acceleration could therefore be considered the predominant pre-movement cardiac activity. Separate 2 condition repeated measures ANOVAs, revealed a significant difference for change in HR, $F(1,101) = 6.40$, $p < .05$, $\eta^2 = .06$, but not rate of HR deceleration, $F(1,101) = 3.00$, $p = .09$, $\eta^2 = .03$, between these revised values for the winner condition and control. Furthermore, variability in the change in HR and rate of HR deceleration for the winner condition as shown in table 4.1, was respectively almost double and four times that of all other conditions. Taken together, this further analysis of the winner condition suggests that HR deceleration may have been affected by this manipulation and that individuals might have been affected to different extents.

	Experimental Condition										
	Control	Dual Task	Task Difficulty			Pressure					
Measure (possible range)			Reduced Distance	Increased Distance	Reduced Target	Leader board	Team Competition	Individual Competition	Winner	*F(8,94)*	*η*^{2}
	Mean (*SD*)										
Performance											
Average Score (0-8)	3.76 (1.22)	3.87 (1.28)	5.47 ^{a} (1.01)	2.26 ^{a} (1.19)	3.02 ^{a} (1.37)	4.16 ^{a} (1.33)	4.17 ^{a} (1.29)	4.35 ^{a} (1.24)	3.75 (2.45)	128.51***	.92
Psychological											
Effort (1-7)	4.40 (1.14)	4.60 (1.34)	4.66 (1.88)	4.75 ^{a} (1.23)	4.74 ^{a} (1.22)	5.30 ^{a} (1.30)	5.40 ^{a} (1.25)	5.41 ^{a} (1.29)	5.54 ^{a} (1.28)	12.84***	.52
Perceived Pressure (1-7)	2.60 (1.28)	3.12 ^{a} (1.52)	2.41 ^{a} (1.33)	2.87 ^{a} (1.54)	2.72 (1.45)	3.31 ^{a} (1.67)	3.26 ^{a} (1.63)	3.37 ^{a} (1.70)	3.58 ^{a} (1.80)	10.54***	.47
Perceived Task Difficulty (1-7)	3.86 (1.33)	5.80 ^{a} (1.33)	3.48 ^{a} (1.84)	5.59 ^{a} (1.38)	5.28 ^{a} (1.43)	4.50 ^{a} (1.44	4.28 ^{a} (1.46)	4.20 ^{a} (1.53)	4.70 ^{a} (1.63)	34.43***	.75
Internal Task-Related (0-100%)	28.53 (17.96)	19.26 ^{a} (14.67)	34.00 ^{a} (17.75)	32.65 ^{a} (14.96)	28.57 (16.99)	31.59 (14.86)	30.12 (14.24)	30.92 (14.99)	29.37 (19.39)	9.02***	.44
External Task-Related (0-100%)	43.91 (18.62)	30.95 ^{a} (18.45)	40.01 (16.80)	40.28 (17.44)	45.23 (17.92)	42.96 (18.00)	42.47 (15.96)	41.26 (17.14)	45.74 (24.56)	5.25***	.32
Internal Task-Unrelated (0-100%)	10.44 (10.73)	13.27 (14.65)	11.10 (11.22)	11.72 (11.97)	10.58 (10.20)	11.06 (10.86)	11.47 (13.43)	11.12 (11.79)	11.99 (15.07)	0.61	.05
External Task-Unrelated (0-100%)	18.18 (16.44)	36.63 ^{a} (24.82)	15.04 (13.99)	16.47 (15.09)	15.79 (15.01)	14.26 ^{a} (12.44)	19.15 (17.55)	16.86 (13.65)	16.01 (18.66)	10.00***	.47
Physiological											
Heart Rate (bpm)	95.46 (12.68)	94.96 (13.29)	92.29 ^{a} (12.76)	92.04 ^{a} (12.26)	91.04 ^{a} (12.24)	94.59 (13.26)	92.87 ^{a} (12.29)	96.55 (14.13)	98.38 ^{a} (13.57)	11.76***	.50
SDNN (ms)	65.94 (25.31)	57.66 ^{a} (22.03)	63.06 (23.01)	60.92 ^{a} (21.32)	58.77 ^{a} (19.35)	60.41 ^{a} (22.18)	57.87 ^{a} (19.07)	62.77 (23.92)	53.54 ^{a} (25.92)	6.58***	.36
r-MSSD (ms)	39.13 (23.36)	34.43 ^{a} (18.67)	38.62 (20.61)	38.49 (18.14)	37.71 (18.37)	36.79 ^{a} (20.51)	35.27 ^{a} (16.35)	36.88 ^{a} (17.24)	29.76 ^{a} (18.01)	5.33***	.31
Rate of Heart Rate Deceleration (bpm)	-11.22 (50.32)	-27.75 ^{a} (41.59)	-13.37 (47.54)	-21.08 (50.93)	-15.03 (54.05)	-21.48 (50.70)	-18.94 (51.83)	-17.41 (52.39)	14.79 ^{a} (100.77)	3.44**	.23
Change in Heart Rate (bpm)	1.22 (5.45)	3.01 ^{a} (4.51)	1.45 (5.15)	2.28 (5.51)	1.63 (5.86)	2.33 (5.49)	2.05 (5.62)	1.89 (5.68)	-1.60 ^{a} (10.92)	3.44**	.23

Table 4.1: Mean *(SD)* of the measure of each pressure condition. Note: ^{a} indicates significant difference from the control condition. ***$p < .001$, ** $p < .01$, * $p < .05$.


A
Control (a)
Dual Task (b)
Mean Heart Rate Change (beats per minute)
Time From Impact with Dart Board (seconds)
4
3
2
1
0
-1
-2
-3
-4
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
a
b
a
b


B
Control (a)
Reduced Distance (b)
Greater Distance (c)
Reduced Target (d)
Mean Heart Rate Change (beats per minute)
Time From Impact with Dart Board (seconds)
4
3
2
1
0
-1
-2
-3
-4
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
a
c
d
b
b
d
a
c

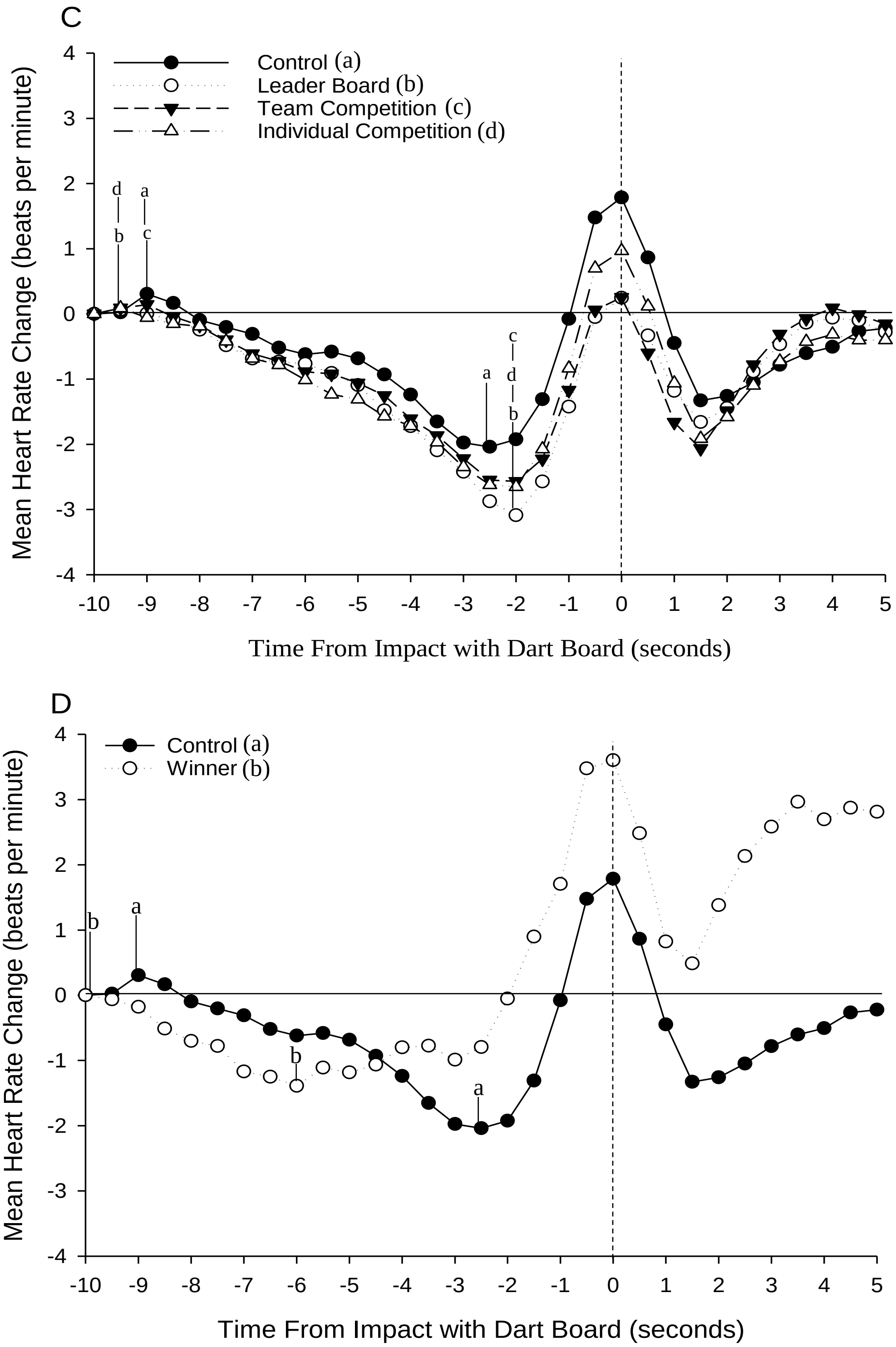


Figure 4.1: Mean heart rate (HR) change relative to 10 s before impact during a 15 s recording period for the control and experimental sub-theme conditions of (A) a dual task, (B) task difficulty, (C) pressure, and (D) single trial pressure. $^{a, b, c, d}$ indicate paired epochs where the difference in pre-movement initiation HR was greatest in each condition. These timings represent the values used to calculate change in HR and the rate of HR deceleration.

Discussion

Under the premise that task difficulty, pressure, and a dual task paradigm have the potential to disrupt attentional processes by altering the prevalence of external or internal focus, the present research employed psychophysiological methods to further explore how preparatory bradycardia may link to preparation for action and choking theories. In line with the hypothesis, performance worsened in more difficult tasks. However, contrary to my predictions, no change in HR deceleration was observed for conditions where performance worsened. Furthermore, the rate of HR deceleration increased in the dual task condition where internal task-related focus of attention decreased. Although performance did not change in the winner condition, it was the only manipulation to produce increased tonic HR in response to increased pressure. Whilst the cardiac measures employed in the current work do not indicate changes in the winner condition, pre-movement acceleration began much earlier and suggests some sort of disruption to attentional processes compared to control and other experimental conditions. Furthermore, variability was notably greater in this condition for both cardiac measures. Accordingly, and as expected, the isolated pressure, task difficulty and dual task conditions induced different effects on each of the psychophysiological measures. The implications of these effects are discussed in greater detail below.

The Psychophysiological Effects of Task Difficulty on Performance

As expected, performance improved in the easiest condition and was impaired in the harder conditions. In the easiest task, moving participants closer to the target in the reduced distance condition will have facilitated a greater margin of error in skill execution, i.e., technical errors associated with releasing the dart on a less optimal target line will not have been as apparent as the dart did not have as far to travel. Therefore, a badly aimed/released throw would not have produced as poor a performance as in the control condition. The same account can explain why performance decreased in the increased distance condition, for example if a dart was released at the optimal height but 3 degrees laterally offline from the centre of target, a calculated trajectory suggests the participant would score 7, 6 and 3 points in the reduced distance, control and increased distance conditions respectively. These results indicate that the manipulations were successful in altering performance as a function of task difficulty and are in line with previous studies showing that increased task difficulty impairs performance (Carroll *et al*., 1986).

Increased task difficulty has been shown to induce pressure (Stoker *et al*., 2017, 2019), which as some research argues (Baumeister, 1984; Eysenck & Calvo, 1992; Masters, 1992), could lead to incidents of choking. This stance could offer an alternative explanation for the decrease in performance observed in the more difficult task conditions. Whilst participants only reported feeling more pressure in one out of the two increased task difficulty conditions, effort increased in both the increased distance and reduced target conditions. According to processing efficiency theory (Eysenck & Calvo, 1992), anxiety as a result of pressure and effort can impair attentional processes integral to optimal performance. More specifically, whilst increased effort is associated with the allocation of additional processing resources, anxiety can overload the working memory i.e., it may be that the greater expenditure of effort seen in this study as result of participants trying harder in more difficult tasks, caused an increase in conscious motor control. This perspective is also reflected by an increase in internal task-related attentional processes in the increased distance condition. As a result of moving further away from the target, participants reported greater focus on internal factors such as, their posture, joint position, and grip tension. The theory of reinvestment (Masters, 1992) further supports the influence of attentional disruption on performance, as participants are susceptible to choking when they reinvest explicit knowledge or controlled processing in an attempt to try harder and do well. However, internal task-related focus of attention was also found to increase in the reduced distance condition where performance improved, and pressure decreased. This contradictory finding could indicate that an increased internal focus of attention in the conditions where the distance of throw was manipulated, may have been more likely to result in an increase in planning and programming of arm movement to alter force production. Whilst this could be considered an increase in conscious control, the fact performance did not decrease means it is unlikely increased conscious processing encouraged choking processes. Furthermore, the HR deceleration pattern did not differ from control in any of the task difficulty conditions. In line with Lacey and Lacey's (1970, 1974, 1980) intake-rejection hypothesis, this offers additional support for greater internal focus of attention not being implicated in the disruption of preparation for action attentional processes, and thus, attentional processes were unlikely to have had a detrimental effect on performance in the present study.

Tonic HR was found to decrease in all task difficulty conditions compared to control. As increased HR is a well-established objective measure of pressure (Cooke *et al*., 2010; Oudejans & Pijpers 2009, 2010; Stoker *et al*., 2019), a decrease in HR suggests that participants were feeling relatively relaxed in the task difficulty conditions compared to control. This conflicts with some previous findings, where HR has been shown to increase as a function of task difficulty (Carroll *et al*., 1986), but concurs with Stoker *et al*., (2017), where no effect of task difficulty on HR was found unless a consequence for poor performance was introduced in addition to a more difficult task. Anxiety has been shown to increase where the demands of the task outweigh skill (Eysenck & Calvo, 1992). It could be therefore, that the task difficulty conditions in this study did not evoke enough pressure to induce cardiac related changes because participants believed they possessed the necessary level of skill to be successful.

Similarly, no changes were observed for either measure designed to capture the HR deceleration profile as a result of manipulating task difficulty. Given the theoretical association between attentional processes and preparatory bradycardia discussed previously, it may be expected that the changes in preparatory cardiac activity should have accompanied increased levels of internal task related attentional focus reported in more difficult conditions. However, whilst cardiac deceleration has been observed in both novice and expert participants, a more pronounced bradycardia seems to be a function of greater expertise (Neumann & Thomas, 2009). As such, the attentional effects on HR deceleration could have been masked by the novice ability of participants. Regardless of the theoretical implications, and although the 2 bpm change in heart rate observed in the present research is somewhat comparable with previous work (Neumann & Thomas, 2009), if HR deceleration is generally more prominent in expert performers, then the disruption of preparatory cardiac activity in novices may have been too small to detect in this study. Future work should focus on expert cohorts with more consistent pre-performance routines, preparatory cardiac patterns, and attentional processes to further explore the relationship between bradycardia and attentional processes. Taken together, the inconsistent psychophysiological responses to varying task difficulty conditions in this study, suggest the most likely reason for performance having been affected by task difficulty, is simply a result of the increasing technical demands.

The Psychophysiological Effects of Pressure on Performance

Contrary to the hypothesis, none of the isolated pressure conditions impaired performance, instead performance increased in three out of the four pressure-based manipulations. Ecologically, this corresponds to the spectacular performances often seen in elite sport when performance excellence is driven by pressure. This finding is in agreement with Stanne *et al*.'s (1999) meta-analysis of competition, where a review of 64 studies suggested that competition led to better motor performances than non-competitive or 'do your best' conditions. Furthermore, performance was observed to be better in scenarios where high means interdependence (see Kavussanu *et al*., 2021) was combined with cooperative goal structures compared to individually performed activities. These nuances have been empirically observed in both skilled motor (Tauer & Harackiewicz, 2004) and endurance performance (Cooke *et al*., 2013). These studies also highlight the importance of effort in competitive performance. Cooke *et al*., (2013) found effort partially mediated the beneficial effects of team competition, whilst Tauer and Harackiewicz (2004) similarly concluded that improved performance in the competitive team scenario was accompanied by an increase in enjoyment levels, which in turn was responsible for mobilising effort – a key determinant of better performance. The fact that tonic HR decreased in the team competition during the present study, suggests that participants were in a relaxed state and potentially exhibiting beneficial levels of enjoyment. Taken together with the present findings, these studies support that increased effort may have positively influenced performance in the competition-based conditions.

The mid-band frequency correlate, SDNN, has previously been employed as an objective measure of effort in psychophysiological methodology (Mulder, 1992). In the present study, an increase in effort in all pressure conditions was reflected in a decrease in SDNN in three out of the four pressure manipulations. Whilst this finding supports effort being a main mediator of performance under pressure in the current study, a decrease in HR variability could also be indicative of increased anxiety (Fortes *et al*., 2017), and thus, may empirically identify a feeling of pressure in these conditions (see Mullen *et al*., 2005 for link between anxiety and pressure). As such, the diminished HR variability seen in the current study could signify less flexibility within the autonomic nervous system to respond to new stimuli, and therefore, perhaps indicates that participants were not in an optimal psychophysiological state for performance. This notion is further supported by the other physiological measures employed in this study. The second indicator of HR variability, rMSSD, decreased in all pressure conditions. Arguably, this measure may be a better indicator of a pressurised state, as rMSSD in short-term recordings is indicative of vagal influence on the parasympathetic nervous system – which is inherently linked to performance under pressure. In essence, when rMSSD is lowered, it means there is less vagus nerve activity, and thus, the body begins to enter an unrelaxed physiological state e.g., HR increases. Moreover, with tentative evidence to suggest HR acceleration was present in the winner conditions, an increase in HR immediately prior to skill execution in these conditions could be indicative of anxiety in the period before participants performed (see Åstrand *et al*., 2003 for link between anxiety and elevated HR). However, tonic HR and the two measures which described HR deceleration did not change in the leader board condition compared to control, and conversely tonic HR decreased in the team competition even though pressure was found to increase in all pressure manipulations. This inconsistency casts doubt over whether cardiac changes were a result of pressure in the present study. However, it could be that the methodology did not produce sufficient pressure to influence physiological differences in all pressure-based conditions. In further support of this suggestion, previous studies which have observed a decline in performance as a result of increased pressure, have done so by applying multiple pressures simultaneously (Stoker *et al*., 2017).

Figure 4.1 and some statistical analysis suggest HR acceleration started earlier relevant to skill execution in the winner condition. An increased standard deviation in change in HR and the rate of HR deceleration in this condition, also indicates greater variability within the two descriptive measures of preparatory cardiac activity. Whilst HR acceleration has been noted in the period immediately following skill execution (Cooke *et al*., 2014; Neumann & Thomas, 2009), HR acceleration being the prominent cardiac output in the immediate seconds before some participants threw the dart in the winner condition, is unusual. According to the intake-rejections hypothesis (Lacey & Lacey, 1970, 1974, 1980) this cardiac pattern suggests participants were engaging in limited external focus of attention processes in the seconds preceding the dart throw. However, no changes in the attentional measures were observed, and thus, non-attentional related theories such as Obrist's (1968) cardiac-somatic uncoupling concept, could provide a better explanation for the observed tachycardia in the winner condition. This model suggests that instead of promotion of the bulbar restraint upon the reticular formation reducing cortical response to external stimuli (Hatfield, *et al*., 1987), HR acceleration is caused by increased muscle and metabolic activity in the seconds before movement initiation. Conclusions from this perspective are limited though, as no measure of muscle or metabolic activity was employed during this study.

Despite the conflicting mechanistic principles of Lacey and Lacey's (1970, 1974, 1980) and Obrist's (1968) theories, the relationship of both paradigms with expertise suggest that HR deceleration may be beneficial for performance, and thus, HR acceleration may be detrimental. As previously discussed, attentional processes are implicated in the breakdown of skill under pressure (Baumeister, 1984; Eysenck & Calvo, 1992; Masters, 1992). As such, if HR deceleration is indicative of external focus, HR acceleration in the winner condition could be indicative of choking. However, performance did not change compared to control. Therefore, whilst HR acceleration and the other cardiac measures may indicate participants felt under pressure during the winner condition, the psychophysiological interference was not strong enough to induce choking. Furthermore, greater variability in the winner condition in terms of rate of HR deceleration and change in HR imply that individuals may have responded differently to pressure in this condition. For instance, whilst group level analysis indicate HR acceleration was the prominent feature of cardiac activity between 6 s and 2.5 s before impact with the dart board, at an individual level it would appear that 44% of participants actually exhibited HR deceleration in the winner condition during this time frame.

These differences highlight two important challenges within pressure research. Firstly, historically isolated pressure conditions have been considered as equal and additive (Baumeister, 1984). The present results contradict this position and suggest that different types of pressure can evoke different responses. As demonstrated by the winner condition, not only can different types of pressure cause differing psychophysiological effects, but aggregated data may render results insignificant. Whilst changes in HR deceleration were expected to emerge in the presence of pressure, the single trial winner condition was the only pressure-based manipulation where changes to the preparatory cardiac pattern were observed. Secondly, individuals can experience different psychophysiological effects in response to pressure, and as such, pressure can impact performance on an individual basis. Future work should consider these perspectives during methodological design and seek to further explore implications in terms of the type of pressure applied and individual response to pressure.

The Psychophysiological Effects of a Dual Task Paradigm on Performance

The dual task condition was designed to limit disruption of attentional processes. In essence, the use of a secondary task should have protected participants from increased conscious processing (Masters, 1992) and/or reinvestment (Baumeister, 1984), as the working memory would have been occupied with the additional cognitive task. Furthermore, if HR deceleration is indicative of external focus of attention, then the prevention of these processes which are synonymous with internal focus of attention (Gray, 2004) should have produced a more robust preparatory bradycardia. In line with these hypotheses, external task-unrelated attentional focus significantly increased at the expense of internal and external task-related attentional focus in the dual task condition compared to control. The rate of

HR deceleration also increased compared to control. Although no other conditions in the experiment produced similar results, these results in the dual task condition strongly implicate the rate of HR deceleration may be indicative of attention processes. One possible explanation for this discrepancy originates in the skill acquisition literature (Fitts & Posner, 1967). As participants in this study were all novices, they were likely at a declarative stage of learning which involves explicit encoding of knowledge normally resulting in conscious processing, and thus, internal focus of attention. HR deceleration may not have been affected in other conditions, because internal focus of attention was the consistent and predominant attentional process. As indicated above, the dual task condition meant participants did not have an opportunity to engage in internal focus of attention, so whilst HR deceleration was not more pronounced, it was more efficient. The ability to prepare for action more efficiently is another key characteristic of expertise (Fitts & Posner, 1967), and thus, implies that a quicker rate of deceleration could be beneficial for performance. The constraints of the dual task meant participants were asked to engage in a secondary task by verbally responding every 60 s to a metronome. To maintain performance levels by limiting potential distraction during this condition, participants may have purposefully chosen to perform between task prompts. Whilst the methodology of the current study does not facilitate this analysis, the greater rate of HR deceleration in the dual task condition may be indicative of participants performing dart throws between prompts, and thus, having less time to engage in potentially detrimental attentional processes meant they were able to plan and programme their skilled motor performance quicker and more effectively. Although expertise is linked to greater bradycardia in the seconds before skill execution, and as such, suggests a link to superior performance, performance did not change in the dual task condition compared to control. Therefore, it remains unclear whether the novel cardiac pattern observed in this condition is beneficial for performance in novice participants.

Limitations and Future Directions

In addition to points noted in the narrative above, there are several limitations to the present study. Firstly, novice and expert HR deceleration has been shown to differ by 10 bpm (Neumann & Thomas, 2009). Although the novice participants in the present research reflected previous work by exhibiting a HR deceleration of around 2 bpm, a reduced cardiac deceleration profile may be less susceptible to influential factors, such as pressure and task difficulty. Similarly, because novices are likely exhibiting greater baseline levels of internal focus of attention, disruptive effects of pressure and task difficulty on attentional processes (e.g., increased conscious processing) may be less apparent. Future work should therefore focus on extending this methodology to higher skilled participants, where HR deceleration in the seconds preceding skilled motor performance is likely to be more established, and attentional processes could be more susceptible to increased pressure and/or task difficulty.

Secondly, inconsistent findings in terms of HR deceleration as a result of high inter- and intra-individual variability (e.g., Lykken *et al.,* 1966) may also hinder this type of research and render the findings in this study underpowered for analysis purposes. For instance, Hassmén and Koivula (2001) found that low anxiety groups exhibited more pronounced HR deceleration compared to a high anxiety group of equal ability when exposed to noise and different levels of task difficulty. In terms of attentional focus, individual differences in tendency to increase self-focus and reinvest has also been shown to influence performance (Baumeister, 1984). Future work should measure predisposed tendencies to help account for inter- and intra-individual variability through inter-group or multi-level modelling analysis.

Finally, the influence of respiration on cardiac activity must be a consideration in this area of research. Respiratory sinus arrythmia is a physiological reflex which describes the natural HR deceleration seen in response to exhalation, and thus, underlying respiratory patterns will always be a limitation when investigating this cardiac phenomenon. Elite and novice participants have previously been shown to favour an exhalation pattern prior to skilled motor execution (Neumann & Thomas, 2009), so future research should measure respiration to help fully support psychological explanations for preparatory bradycardia.

Conclusion

In conclusion, the present study confirms that performance, and various psychological and physiological measures can be affected by pressure, task difficulty, and dual task demands. Although the novice cohort may have limited further understanding of how attentional processes link to the HR deceleration pattern seen in the seconds preceding skilled motor performance, the findings presented provide tentative evidence that preparatory bradycardia may be affected by pressure. Furthermore, an increase in the rate of HR deceleration in the dual task paradigm implicates this cardiac pattern as an objective measure of more effective external focus of attention (Lacey & Lacey, 1970, 1974, 1980), and suggests a link to attentional efficiency. Given recurring limitations regarding physical influences, future work may wish to explore the intake-rejection hypothesis theory in more physically demanding tasks to help remove the possibility of physiological reflexes explaining HR deceleration (e.g., Obrist, 1968).

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CHAPTER FIVE

The Effect of Expertise, a Dual Task, Task Difficulty, and Pressure on Preparatory Cardiac Activity and Attentional Processes in Golf Performance

Abstract

Previous research has established heart rate (HR) deceleration in skilled motor tasks (Neumann & Thomas, 2009, 2011; Tremayne & Barry, 2001). The intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) describes the proposed relationship between preparatory bradycardia and attentional processes. Under the premise that increased task difficulty, greater pressure, and the introduction of a dual task could manipulate attentional processes, this study aimed to explore pre-performance cardiac activity in a more physically demanding skilled motor task; a full golf swing. Under control conditions, expert (*N* = 20) golfers were found to exhibit HR deceleration, but intermediate (*N* = 20) golfers did not. This finding could further substantiate the intake-rejection hypothesis, as the difference in bradycardia is synergistic with attentional characteristics of expertise (Fitts & Posner, 1967). Experts then performed in seven separate conditions designed to manipulate attention. Condition was found to have a main effect on the magnitude and rate of HR deceleration. These two cardiac measures were found to be significantly less in the single trial pressure condition compared to control, to the extent that HR acceleration was conversely observed. Despite these varying psychophysiological responses, expert performance remained consistent across conditions. Whilst the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) was supported by some findings, certain conditions contradicted this hypothesis. Individual differences and methodological design may account for these inconsistencies.

Introduction

Performance Under Pressure

Pressurised environments (e.g., emergency surgery, military snipers, and elite sport) can evoke excellence. The pressure to perform can stem from *'any factor or combination of factors that increases the importance of performing well on a particular occasion'* (Baumeister, 1984). Elite sport in particular is often defined by spectacular performance, and regardless of the underlying rationale, it is generally agreed that the desire to succeed can elicit pressure to perform (Beilock & Carr, 2001). However, empirical (e.g., Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992) and anecdotal (e.g., England Senior Men's Football Team in major tournament penalty shoot outs, Jimmy White at the World Snooker Final in 1994, and Gavin Hastings in the 1991 Rugby World Cup Semi-Final) evidence suggest that individuals can underperform when presented with pressurised scenarios. The phenomenon of not being able to maintain performance under pressure in this context is often referred to as 'choking' (Beilock & Gray, 2007).

The disruption of attentional processes has been implicated in the mechanistic theories of choking (e.g., Baumeister, 1984, Masters, 1992). For example, Baumeister (1984) suggested that an increase in self-focus leads to performers consciously controlling skill under pressure, but that "*consciousness does not contain the knowledge of these skills, so it ironically reduces the reliability and success of performance*". Similarly, Masters (1992) proposed that individuals may exhibit greater conscious processing or reinvest explicit knowledge under pressure in order to achieve optimal performance, however these processes can reduce skill, and thus, choking can occur. Meanwhile, anxiety is almost always present during incidences of choking under pressure in sport (Mullen *et al*., 2005). In combination with Baddeley's (1986) tripartite model of working memory, processing efficiency theory (Eysenck & Calvo, 1992) connects pressure, anxiety, and effort in relation to attentional processes. When pressure induced anxiety affects the central executive of working memory, together, these theories assume that ability to retain on task attention diminishes because auxiliary capacity has been consumed, and thus, performance is likely to be impaired. In sum, the literature exploring choking under pressure implies that an increase in anxiety and/or self-focus, has the potential to disrupt attentional processes and detrimentally affect skilled motor performance as a result.

The Intake-Rejection Hypothesis

Whilst numerous mental skills practices have been developed to support athletes maintain optimal performance under pressure (see Locke & Latham, 1990; Singer *et al*., 1993; Vealey, 2007), these methods are often reliant on observations, subjectivity, and self-report data (e.g., Masters *et al*., 2005). Psychophysiology could provide a more objective measure of performance processes (Collins, 2002; Cooke & Ring, 2019), such as attentional focus. The constrained action hypothesis (Wulf *et al*., 2001) describes the potential benefits of external focus of attention for skilled motor performance. Phasic bradycardia in the seconds preceding skilled motor performance is proposed to reflect external focus of attention and is described by the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980). Heart rate (HR) deceleration immediately prior to skilled motor execution, is proposed to unload the baroreceptors by reducing blood pressure and thereby create a greater flow of environmental information to the brain (Brunia, 1993). Conversely, HR acceleration during this period may reduce the cortical response to external stimuli by inducing promotion of the bulbar restrain upon the reticular formation (Hatfield *et al*., 1987), and therefore could be suggestive of internal focus of attention.

The relationship between preparatory bradycardia and attentional processes was originally derived from historical reaction time studies (Lacey & Lacey, 1970, 1974, 1980), but more recently HR deceleration in the seconds preceding skilled motor performance has been confirmed (Cotterill & Collins, 2005; Neumann & Thomas, 2009). Elite, experienced, and novice golfers have been observed to exhibit 12, 10, and 2 beats per min (bpm) HR deceleration respectively in the 6 s before putting (Neumann & Thomas, 2009). The difference seen in magnitude of HR deceleration exhibited as a function of expertise, has also been observed in pistol (Tremayne & Barry, 2001) and rifle shooting (Hatfield *et al*., 1987). This expert novice contrast is consistent with learning paradigms and adds more support to the argument that this cardiac pattern may be indicative of external focus of attention. Expert performers are more likely to pay attention to external cues as movement planning and programming is more automatic. Contrastingly, novice performers need to consciously control movement, and thus, in comparison exhibit increased levels of internal attentional focus to correctly execute a skilled motor task (Anderson, 1982; Fitts & Posner, 1967). Empirically, evidence from Radlo *et al*., (2002) indicated that performance improved when novices were asked to focus their attention externally during a dart throwing task and HR deceleration was found to be more pronounced. Nevertheless, whilst this study confirmed a greater magnitude of bradycardia in more skilled participants, later work unexpectedly found no HR deceleration differences between attentional focus goal setting groups in elite, experienced, or novice golfers (Neumann & Thomas, 2011).

Whilst this body of work provides contemporary support for the intake-rejection hypothesis, the cardiac-somatic coupling and uncoupling theory (Obrist, 1968) questions the relationship between preparatory bradycardia and attentional focus. This model alternatively suggests that HR deceleration is reflective of reduced muscle and metabolic activity. Studies in golf putting have however confirmed that arm muscle activity conversely increases prior to movement initiation (Cooke *et al*., 2014). In extension of this perspective, Cotterill *et al*., (2010) found that golfers generally exhibit rehearsal movements, such as practice swings, as part of pre-performance routines. As such Obrist's theory appears somewhat unsupported in a sporting context.

The Present Study

Given the physiological reflexes associated with increased metabolic demands as a result of physical activity (see Horn & Swanson, 2013), previous research has focused on relatively low physically demanding tasks. Expanding understanding of preparatory bradycardia in more complex and physically demanding tasks, may help to further validate the intake-rejection hypothesis. Prospective voluntary control of the somatic nervous system has been observed in some scenarios where preparation for physiological effort is advantageous (Benum *et al*., 2021; Decety *et al.,* 1993; McArdle *et al*., 1967). For instance, athletes have been shown to exhibit an increase in HR prior to the start of a race in sprinting (McArdle *et al.*, 1967) and biathlon (Benum *et al*., 2021). In relation to the present work, if athletes exhibit HR deceleration despite potentially being expected to voluntarily increase HR to help perform an explosive skill (e.g., full golf swing), then it grows ever more unlikely that cardiac deceleration is a result of physiological influences.

With the disruption of attentional processes inherently linked to choking under pressure (Baumeister, 1984; Eysenck & Calvo, 1992; Masters, 1992), it is surprising that preparatory bradycardia has been relatively unexplored in this context. Traditional methods of inducing pressure experimentally involve manipulating the task, the environment, and/or the performer. In terms of task manipulation, previous work has determined that increased task difficulty can cause a rise in tonic HR (Carroll *et al.,* 1986). However, Stoker *et al*., (2017) found that an increase in HR was only present in more difficult conditions if a consequence of poor performance was concurrently applied. Attentionally, planning and programming processes have been shown to be more automatic in easier tasks (Landers *et al*., 2005). Taken together, these findings suggest that cardiac activity and attentional processes can vary as a function of task difficulty. The manipulation of task difficulty may therefore be a valuable paradigm, to aid further exploration of the relationship between preparatory bradycardia and external focus of attention.

Ecologically, pressure is often most synonymous with competition (Baumeister & Showers, 1986; Martin & Hall, 1997). Depending on the competitive scenario, pressure induced anxiety is commonly associated with consequences such as, punishment, reward, and/or evaluation. Despite recent research (Stoker *et al*., 2017, 2019; Mesagno *et al*., 2011) challenging the longstanding assumption that all pressures elicit equal effects (Baumeister, 1984), previous work has shown that individual sports generally evoke greater pressure than team sports (Martin & Hall, 1997). However, ego-threat may have the potential to induce choking under pressure when performers are faced with an individualistic scenario that could directly affect teammates (Baumeister, 1997). Whilst uncertainty remains as to whether competition has a facilitative or debilitative effect on performance, competition has nevertheless been found to enhance performance compared to individualistic scenarios (Stanne *et* *al*., 1999). Physiologically, tonic HR has been shown to increase in cooperative and individual competitive settings (Veldhuijzen van Zanten *et al*., 2002). Combined with self-focus mechanistic theories of choking (Baumeister, 1984; Masters, 1992), these findings imply that performance may be subject to different effects dependant on the competitive scenario, but that pressure derived from competition could disrupt attentional processes. Ultimately, as choking is indicative of increased self-consciousness (Baumeister, 1984; Masters, 1992), if HR deceleration represents external focus, the intake-rejection hypothesis may be further supported by changes to preparatory bradycardia when performance declines in competitive scenarios.

Whilst dual task manipulations are not generally considered to directly induce pressure, they are a validated technique for manipulating attentional focus in psychophysiological research. Secondary tasks in a performance environment protect performers from reinvestment by placing demands on short-term memory capacity, so that explicit skill knowledge is unable to accumulate. For instance, skill-focus instructions were found to reduce performance in golf-putting and football dribbling compared to when participants performed whilst completing a secondary task (Beilock *et al*., 2002). Gray (2004) also found that performance was worse in expert baseball batters when they were asked to focus on their movements compared to completing a secondary task whilst hitting. Moreover, the protective effects of a secondary task seem to remain when individuals are asked to perform under pressure (Jackson *et al*., 2006). Whilst it is unclear how a dual task may affect physiological measures, given that this protocol seems to limit internal focus of attention, it could provide another valuable method for further exploring the intake-rejection hypothesis.

Under the premise that increased task difficulty, separate competitive pressures, and a secondary task could affect attentional processes, the present study used a within-participant design to further explore preparatory cardiac activity. In contrast to Baumeister’s (1984) extensively cited paper on pressure, the use of separate pressure conditions also aimed to provide further evidence for the recent movement towards pressure not being equal (Mesagno *et al*., 2011; Stoker *et al*., 2017). Furthermore, although most research thus far has studied HR deceleration in low physically demanding tasks, given the physiological implications proposed by Obrist (1986), the current work employed a more explosive movement. Lacey and Lacey’s (1970, 1974, 1980) perspective could be further substantiated if HR deceleration is established prior to a full golf swing, as the autonomic nervous system may be expected to have opposing influences. In line with the intake-rejection hypothesis and the notion that external focus of attention is a feature of expertise and successful performance, it was hypothesised that HR deceleration would be greater in expert than intermediate performers under control conditions. Tonic HR was expected to increase with pressure and task difficulty, and it was proposed that preparatory bradycardia would be compromised in conditions where performance worsened. Conversely, HR deceleration during the dual task was expected to be similar to control conditions, as working memory capacity would be consumed and a shift to internal focus of attention would therefore not be possible. Performance was meanwhile anticipated to be less consistent as a function of task difficulty and in conditions where pressure reached a level that would leave participants susceptible to choking.

Method

Participants

Expert (Male = 19, Female = 1) and intermediate (Male = 14, Female = 6) participants were recruited based on handicap (*M* Expert Handicap= 0.49, *SD* = 3.31; *M* Intermediate Handicap = 15.70, *SD* = 5.01). Difference in group ability was confirmed by a one-way analysis of variance (ANOVA) test on handicap, $F(1, 38) = 128.52$, $p < .001$, $\eta^2 = .77$. Intermediate participants with a formal handicap were selected for this study rather than novices due to the technical nature of the task. Furthermore, previous research (Neumann & Thomas, 2009) has confirmed significant differences in preparatory HR deceleration patterns between experienced and elite golfers. The protocol was approved by the local research ethics committee and all participants (*M* Age = 29.95 years, *SD* = 13.93) provided informed consent.

Task

Participants performed a series of full golf shots in an indoor golf simulator comprising of a projector screen and artificial turf mat. The screen displayed an unmarked driving range or a circular green with target flag depending on the condition. Golf has been used in several attention studies (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas 2009, 2011) as it relies heavily on skilled performance. Previous work has employed putting as the main experimental task. The present work aimed to extend understanding of the relationship between attentional processes and HR deceleration by using a physically more demanding full golf swing. Accurate planning and movement programming remained integral to the successful performance of this task, meaning attentional processes were likely prevalent.

Performance Measures

The simulator was equipped with a ball flight launch monitor (Foresight Sports' GC2). Five variables were recorded which indicated velocity just after impact (Ball Speed, mph), the initial vertical angle of ascent relative to the ground (Launch Angle, degrees), and components of total spin which define ball lift/trajectory (Back Spin, rpm) and ball curvature/shot shape (Side Spin, rpm). A combination of these measures then informed a distance variable (Carry, yards). With consistency a significant characteristic of expertise (Fitts & Posner, 1967), these five trajectory variables were considered in combination for analysis purposes.

Psychological Measures

Pressure and effort. The effort/interest and pressure/tension subscales of the Intrinsic Motivation Inventory (Ryan, 1982) were used to determine effort, perceived task difficulty, and pressure in a post-task questionnaire. The items "*I tried very hard to do well*" and "*It was important to me to do well*" were used to establish effort, whilst "*I found the task difficult*" was the singular measure of perceived task difficulty. These measures were employed to determine participant engagement and whether greater effort was associated with increased task difficulty and/or pressure tasks. Pressure was characterised using 4-items; including "*I felt nervous*" and "*I felt pressured*". This measure allowed further exploration of previously established relationships between pressure and task difficulty (Carroll *et al.*, 1986), and pressure and competition (Veldhuijzen van Zanten *et al.*, 2002) in the context of the intake-rejection hypothesis. All items were ranked using a 7-point Likert scale anchored by 1 "*not at all*" and 7 "*very true*". The internal consistency of the adapted effort and pressure subscales were both very good ($\alpha = .81$ to .92 and $\alpha = .89$ to .95 respectively).

Attentional Processes. To further explore the relationship between preparatory bradycardia and attentional processes, a focus of attention pie chart (Appendix 1B) was also included in the post-task questionnaire to help establish where participants were focusing their attention prior to shot execution. Participants were asked to split an unmarked circle into segments to represent what extent they focused on certain factors before performing. This measure provided parallel ratings for four types of attentional focus: internal task-related (e.g., posture, joint position, grip tension), external task-related (e.g., the golf club, ball, or target), internal task-unrelated (e.g., breathing, hunger, body temperature), and external task-unrelated (e.g., general surroundings, noise, the experimenter).

Physiological Measures

Cardiac. To unobtrusively explore cardiac variables in the seconds preceding performance, an electrocardiogram was recorded using a wireless sensor system (Delsys® Truigno IM^{TM}) in a modified three spot electrode configuration. The recording was imported and analysed using Spike2 software (Cambridge Electronic Designs). Although R-wave peaks were automatically identified by an interactive program, visual inspection and manual movement of scored points ensured correct identification. R-R interval analysis confirmed HR at 0.5 s increments from 10 s before to 5 s after impact with the ball. This recording time reflects previous work by Neumann and Thomas (2009), who similarly aimed to characterise cardiac activity in the seconds preceding skilled motor performance.

Tonic HR (Heart Rate) was calculated using the mean output from across these time points in each condition. Pairwise comparisons from separate 31 epoch repeated measures ANOVAs were used to determine the epoch where the highest and lowest HR for each ability group in each condition was recorded. Change in HR reflected the difference between these two extremities of HR relative to impact with the ball i.e., the max/min point closest to impact with the ball (generally where deceleration began at a group level in each condition) was always subtracted from the max/min point furthest away from impact with the ball (generally where acceleration began at a group level in each condition), and therefore represented the magnitude of HR deceleration. The rate of HR deceleration looked at the gradient of the bradycardia profile and was calculated in the same way as change in HR, but the value was further divided by the difference in time between epochs corresponding to the HR min/max points (converted to mins to correspond with the HR unit, bpm). These variables in combination indicated how quickly and to what extent HR changed in the seconds immediately before each shot.

Conditions

Control. Participants were asked to hit five shots with an 8-iron. Biomechanically, shorter clubs (e.g., Pitching Wedge, 9-iron, 8-iron, 7-iron) are easier to hit consistently, as the greater face angle tends to be more forgiving even when the strike quality is poor. To encourage a meaningful amount of variance for statistical analysis, use of an 8 iron throughout therefore helped to facilitate a good level of performance in both abilities. Furthermore, commercial golf club manufacturers design clubs to suit different swing types, genders, and physical capabilities. Players, particularly those who are less skilled, may struggle to use clubs not suited to them as a result. Hence, in order to best characterise a ‘normal’ shot, participants were instructed to use their personal 8-iron unless otherwise instructed. All shots were hit from the artificial grass surface rather than a golf tee to mimic a standard 8-iron fairway shot. The indoor golf simulator was arranged in a standard setup (Foresight Sport) with the artificial hitting mat (1.5 m square) located 3.6 m from the projector screen (3.7 m x 2.9 m). Whilst participants did not have access to launch monitor data during the experiment, the projector screen provided visual feedback for each shot by displaying a line to mimic shot trajectory. The room was kept at an ambient temperature of around 19 C to reflect pleasant summer golfing conditions and help ensure environment did not affect HR. Participants were asked to complete shots in their own time. To minimise additional physical activity and/or postural changes between shots which could have produced physiological interference, experimenters collected golf balls and placed them on the artificial hitting mat as necessary. Most golfers with on-course playing experience (i.e., all participants in this study) tend to have adopted a pre-performance routine which may contain a variety of physical and/or psychological elements designed to help individuals prepare to perform (Cotterill *et al*., 2010). Whilst attentional processes may habitually differ between participants as a result of varying pre-performance routine behaviours, disruption of these routines can affect performance. As such, participants were asked to perform each shot as they would on course including all aspects of their pre-performance routine.

Dual Task. Participants performed ten shots under control conditions at the same time as performing an additional mental task. Participants were asked to listen to a series of loud low-pitched and high-pitched tones manually controlled by the experimenter, and verbally respond to the high-pitched tones. Whilst the timing of the low-pitched tones was randomised, the timing of high-pitched tones was equally counterbalanced using a Latin square (Williams, 1949). Thus, the response sound either played during participants pre-performance routines before they addressed the ball, or once they had addressed the ball. This methodology ensured that despite participants potentially engaging in different physical and psychological behaviours during pre-performance routines, disruption of attentional processes could occur throughout the preparation period. The addition of a mentally demanding task was designed to manipulate attention, by preventing conscious motor control processes (see Beilock *et al*., 2002; Gray, 2004; Jackson *et al*., 2006).

Ball Below Feet. Competitive golf requires shots to be played on a variety of terrains. For example, shots hit from an elevated position compared to the ball, may require biomechanical adaptation of the golf swing to achieve successful performance, and therefore, can be deemed more challenging. In the present study, task difficulty was increased by introducing a sloped platform to create an elevated hitting stance. All other factors remained the same as control. Previous studies have validated an association between task difficulty and psychophysiological processes, with more difficult tasks associated with pressure and increased tonic HR (Carroll *et al*., 1986).

30% Clubhead. This condition was also designed to increase task difficulty. Participants performed under the same conditions as control, except they were given a specially designed club to use. It had an almost identical face angle but the clubhead was 70% smaller than most commercially available 8-irons. Practically, this meant participants had a smaller area for impact and therefore were required to be more technically proficient/consistent to achieve a successful strike quality.

Leader Board. Control conditions were replicated, but participants were told their total score during this condition would count towards a leader board which would be shared with every participant in their ability group at the end of the experiment. The first placed participant in each ability group would receive a £50 Amazon voucher. This condition was designed to elicit pressure through a performance-contingent reward, competition, and social evaluations; all strong themes of pressure research (Cooke *et al*., 2010, Mesagno *et al*., 2011; Stanne *et al*., 1999). In order to create a score, the projector screen was changed to show a circular green with target flag and a three-shot closest to the pin scenario was introduced. The target flag distance was set by the participant based on their average 8-iron yardage. Participants were permitted three familiarisation shots to check they were happy with the set yardage before proceeding with the condition. A target format was used in all pressure conditions, and meant participants received immediate feedback on performance outcome (radial error from the target) from the experimenter rather than just ball flight trajectory. This change in format and introduction of a clear performance outcome measure was employed to help create the illusion of close competition, and thus, potentially encourage a heightened state of anxiety.

Team. Participants were informed that they had been randomly paired with another participant from their ability group to form a team. The paired team would compete against another team from the same ability group to win a £5 Amazon voucher. Participants were led to believe that their teammate and the other team had already taken part in the experiment. Using scores produced as part of the closest to the pin familiarisation, an achievable target to beat was calculated so that participants were given the impression that the competition was close. When faced with a scenario that will directly affect other team members, it is thought that pressure stemming from ego-threat may cause athletes to perform poorly (Baumeister, 1997).

Winner. As participants could not see their performance data for the team competition, regardless of outcome, the experimenter now informed the participant that they had successfully helped their teammate win in the previous condition and had won a £5 Amazon voucher. However, they were subsequently told that they would now compete against their teammate to win the total team's prize fund. If they were unsuccessful, their teammate would win both £5 Amazon vouchers and they would leave empty handed. An isolated condition for individual competition was important to include in the present study because anxiety has been shown to be greater in individual than team sports (Martin & Hall, 1997).

Nomination. Participants performed under the same conditions as control, except they were only asked to hit one closest to the pin shot. At this point the experimenter informed each participant that they had been randomly selected to take part in an additional condition. If they managed to hit the next shot to within 5 yards of the target, every participant in their ability group would receive a £5 Amazon voucher. 5 yards was selected as the target zone, as pilot data indicated that this would roughly equate to 5% proximity of distance for most participants. 5% proximity of distance is generally the level of approach play PGA tour professionals must perform at to win an event (www.pgatour.com/stats), and therefore represented a challenging but achievable performance target. Whilst scientific research often requires multiple trial protocols to amass data for statistical analysis, ecologically, successful sport performance (particularly involving skilled motor tasks) can often be dependent on one shot, one movement, or one moment in a game. This condition was employed to explore whether differences could be detected in a single trial scenario. It is also likely that with performance outcome dependent entirely on one golf shot, participants would experience greater pressure because the factors inducing pressure would be intensified.

Procedure

To avoid potential influences on cardiovascular activity, participants were asked to avoid caffeine consumption during the 4 h's before their laboratory sessions. Upon entering the laboratory, skin sites were exfoliated and cleaned ready for attachment of electrocardiogram electrodes. Secure attachment ensuring good quality signal output was achieved by employing specialist electrode interfaces and medical tape. Participants completed five shots under the same conditions as control to familiarise themselves with the equipment. Whilst the control, dual task, and two task difficulty conditions were counterbalanced using a Latin square (Williams, 1949), due to the narrative of the pressure conditions, the four pressure conditions were completed in the order set out above. This design also aimed to ensure participants did not become accustomed to pressure during the experiment, with pressure designed to increase as the protocol progressed. A within-participant protocol was applied across conditions. No instructions or suggestions were given prior to, or during the experiment regarding golf swing technique, and all conditions were administered by the experimenter using a script. Participants were asked to complete a self-report questionnaire after each condition, which enabled a rest period of approximately 3 min between conditions. The total number of shots hit during the 2 h protocol totalled 40, which is equivalent to the number of full shots hit in a round of golf for expert golfers. Moreover, all participants were regular driving range users and would therefore have been accustomed to hitting the required number of shots. In sum, whilst participants were not walking between shots as they would in regulation play, there should have been no additional physiological effects associated with fatigue or increased energy expenditure.

Statistical Analysis

In terms of confirming HR deceleration in the seconds before a full golf swing, overall and ability specific repeated measures ANOVAs were employed to investigate the effect of epoch on the preparatory bradycardia pattern during the control condition. The Group x Epoch interaction was further explored using follow up pairwise comparisons to establish when HR changed during the recording period (least significant difference). Significant differences were deemed to exist if comparative values were outside the 95% confidence interval. Separate one-way ANOVAs were used to assess differences in HR at each epoch and for each psychophysiological variable between ability groups. Condition specific effects were explored using separate 8 condition repeated measures ANOVAs. Further analyses were completed using pairwise comparisons to ascertain how performance, psychological, and cardiac measures changed in each condition compared to control. The risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVAs was minimised by reporting significant effects using the multivariate method (Vasey & Thayer, 1987). Partial eta-squared was reported as a measure of effect size, with values of .02, .12 and .26 indicating relatively small, medium, and large effect sizes respectively (Cohen, 1992).

Results

The Psychophysiological Effects of Ability

Table 5.1 (top) describes how experts exhibited greater ball speed, back spin, and carry distance compared to intermediates, but no differences in launch angle were seen between ability groups. This is reflective of expert golf performance, with handicap suggested to correlate with ball speed and carry distance (Fradkin *et al*., 2004). A negative side spin in the expert group compared to a positive side spin in the intermediate group indicates an anticlockwise ball rotation compared to a clockwise ball rotation. Extending analysis across conditions confirmed that experts had a far more consistent ball flight than intermediate participants. Condition was found to have main effects on four out of five ball flight measures in the intermediate group, whilst only one variable was found to differ across conditions for experts. Taken together, these results confirm a more consistent ball flight was exhibited by the expert group in this study. This is reflective of skill acquisition literature (Fitts & Posner, 1967) which suggests that consistency is a characteristic of expertise.

Table 5.1 (middle) shows that the only difference between experts and intermediates in the control condition was perceived pressure. Physiologically, no changes were seen in any cardiac measure when comparing expert and intermediate response (Table 5.1, bottom). However, main effects were found for Epoch, $F(9, 30) = 6.14$, $p < .01$, $\eta^2 = .65$, with both linear $F(9, 30) = 122.86$, $p < .001$, $\eta^2 = .76$,and quadratic $F(9, 30) = 54.68$, $p < .001$, $\eta^2 = .59$, tests proving significant. The main effect for Epoch x Ability was not significant, $F(9, 30) = 0.55$, $p = .90$, $\eta^2 = .65$. However, separate repeated measures ANOVAs revealed that the effect of epoch remained significant for both the expert, $F(9, 30) = 3.49$, $p < .05$, $\eta^2 = .92$, and intermediate, $F(9, 30) = 3.20$, $p < .05$, $\eta^2 = .91$, groups during control. HR change in the seconds preceding and following impact with the ball for both ability groups in the control condition is shown in Figure 5.1.

The Ability x Epoch interaction was further explored to determine changes in HR within each ability group and between groups throughout the HR deceleration profile. Using follow up pairwise comparison analysis derived from separate repeated measures ANOVAs, HR was deemed to be significantly different from baseline (i.e., 0 s) if zero was outside the 95% confidence interval. No pre-shot acceleration was found for either ability. Preparatory HR deceleration was only observed in the expert group where HR was found to be significantly lower from 4 s to 1.5 s before impact with the ball. Acceleration was detected in the expert group from 0.5 s to 5 s after the shot. The intermediate group also showed acceleration during the latter phase of the recording period, but acceleration began before impact with the ball occurred, with HR found to be significantly higher from 0.5 s before impact with the ball to 5 s post-impact.

A series of one-way ANOVAs employed to compare ability groups at each epoch revealed that HR was significantly lower in the experts than intermediates for all time points between 4 s and 1.5 s before impact with the ball. Taken together, these results demonstrate that whilst no initial pre-shot acceleration was found for either ability (unlike previous work in golf putting, Neumann & Thomas, 2009) and post-impact acceleration was similar across groups, preparatory HR deceleration in the seconds prior to shot execution was only found to occur in experts.

Given one of the main aims of the present study was to explore the relationship between preparatory bradycardia and attentional processes, the limited findings in terms of HR deceleration in the intermediate group coupled with inconsistencies in performance data across conditions due to a lack of technical proficiency, suggested further analysis should exclude the intermediate group. Furthermore, focusing on expert performance is consistent with skill acquisition literature, which often explores novel interventions by initially characterising successful expert performance. As such, all subsequent analysis of condition effects only included expert participants.

The Psychophysiological Effects of Pressure, Task Difficulty, and a Dual Task on Expert Performance

As indicated previously, repeated measures ANOVAs (Table 5.2, top) on each ball flight variable showed condition to have limited effects on performance. Side spin proved to be affected by condition, but when considering the five ball flight metrics in combination, overall consistency remained constant across conditions. Table 5.2 (middle) shows the multivariate effect was significant for all psychological measures except internal task unrelated attentional focus. Follow-up pairwise comparison analysis revealed that expert participants perceived all conditions to be more difficult than control, however, effort/interest was only found to increase in the pressure conditions. Whilst an increase in perceived pressure in all pressure conditions compared to control confirmed successful manipulation, the expert group also reported feeling more pressure in the 30% clubhead task difficulty condition. In terms of the attentional pie chart, internal task related attentional focus decreased in the dual task, 30% clubhead, leader board, team, and winner conditions compared to control, whilst external task related attention decreased in the dual task condition but increased in the 30% clubhead condition. Greater focus on external unrelated factors was reported in the dual task and ball below feet condition.

Physiologically, separate 8 condition repeated measures ANOVAs revealed main condition effects for HR, change in HR, and rate of HR deceleration (Table 5.2, bottom). Subsequent pairwise comparisons showed that compared to control, HR increased in the dual task, ball below feet, 30% clubhead and leader board conditions. Change in HR and rate of HR deceleration was only found to differ in the nomination condition compared to control, where HR was conversely found to accelerate prior to shot execution. HR change in the seconds preceding and following impact with the ball for experts in the control and separate experimental conditions is shown in Figure 5.2.

Measure (possible range)	Experts	Intermediates	*F (1,38)*	η^2
	Mean (*SD*)			
Performance				
Ball Speed (mph)	109.98 (7.93)	93.53 (16.83)	15.64***	.29
Launch Angle (degree)	22.13 (2.38)	19.82 (5.32)	3.12	.08
Back Spin (rpm)	6999.78 (621.65)	5698.18 (1438.98)	13.79***	.27
Side Spin (rpm)	-444.74 (515.00)	1146.16 (852.36)	51.04***	.57
Carry (yards)	148.19 (12.43)	116.74 (31.94)	16.84***	.31
Psychological				
Perceived Task Difficulty (1-7)	2.50 (1.54)	2.95 (1.57)	0.84	.02
Effort (1-7)	5.28 (1.20)	5.95 (1.00)	3.75	.09
Perceived Pressure (1-7)	1.66 (0.59)	2.74 (1.32)	11.09**	.23
Internal Task Related (0-100%)	39.75 (18.60)	41.15 (17.03)	0.07	.002
External Task Related (0-100%)	38.65 (12.06)	41.53 (19.07)	0.33	.008
Internal Task Unrelated (0-100%)	10.73 (13.38)	5.88 (9.78)	1.71	.04
External Task Unrelated (0-100%)	10.13 (8.75)	10.70 (13.41)	0.03	.001
Heart Rate				
Heart Rate (bpm)	108.06 (13.24)	102.76 (14.11)	1.50	.04
Change in Heart Rate (bpm)	-3.53 (6.61)	-1.08 (7.59)	1.18	.03
Rate of Heart Rate Deceleration (bpm)	-26.47 (49.60)	-8.13 (59.91)	1.18	.03

Table 5.1: Mean *(SD*) of each measure for expert and intermediate participants under control conditions. ****p* < .001, ** *p* < .01.

	Expert Performance									
	Experimental Condition									
	Control	Dual Task	Task Difficulty		Pressure				*F (7,13)*	η^2
			Ball below feet	30% Clubhead	Leader Board	Team	Winner	Nomination		
Measure (possible range)	Mean (*SD*)									
Performance										
Ball Speed (mph)	109.98 (7.93)	109.09 (8.84)	109.19 (8.56)	111.04 (10.00)	107.68 (9.65)	108.71 (9.31)	108.16 (9.14)	108.14 (10.71)	1.11	.39
Launch Angle (degree)	22.13 (2.38)	22.14 (2.19)	21.81 (1.97)	20.93 (3.65)	22.14 (2.46)	21.82 (2.43)	21.99 (2.43)	21.75 (2.63)	1.63	.49
Back Spin (rpm)	6999.78 (621.65)	6918.87 (613.94)	6962.10 (602.17)	6688.86 (769.12)	6999.18 (760.78)	6841.70 (679.61)	6902.58 (616.56)	6870.00 (721.93)	1.88	.52
Side Spin (rpm)	-444.74 (515.00)	-305.67 (385.81)	-220.55 (376.86)	-526.11 (861.57)	-447.92 (383.99)	-462.65 (455.92)	-347.52 (503.95)	-597.59 (562.45)	5.80**	.80
Carry (yards)	148.19 (12.43)	146.69 (13.72)	147.19 (13.51)	146.82 (21.89)	144.37 (14.75)	146.54 (13.94)	145.67 (14.06)	145.16 (16.48)	0.57	.25
Psychological										
Perceived Task Difficulty (1-7)	2.61 (1.58)	4.72 ^{a} (1.41)	3.83 ^{a} (1.50)	4.56 ^{a} (1.69)	4.20 ^{a} (1.24)	3.85 ^{a} (1.50)	4.00 ^{a} (1.69)	4.25 ^{a} (1.94)	3.35*	.68
Effort (1-7)	5.28 (1.20)	5.20 (1.43)	5.40 (1.05)	5.68 (0.77)	6.10^a (1.25)	5.95 ^{a} (1.18)	6.30 ^{a} (0.91)	6.30 ^{a} (1.26)	6.34**	.77
Perceived Pressure (1-7)	1.66 (0.59)	2.04 (1.25)	1.75 (0.90)	2.36^a (1.29)	2.45^a (1.23)	2.33 ^{a} (1.33)	2.53^a (1.29)	3.09^a (1.84)	3.45*	.65
Internal Task Related (0-100%)	39.75 (18.60)	16.08 ^{a} (14.33)	36.00 (15.36)	25.90 ^{a} (17.78)	23.95 ^{a} (19.76)	25.53 ^{a} (12.79)	26.05 ^{a} (15.42)	26.58 (19.65)	7.15**	.81
External Task Related (0-100%)	38.65 (12.06)	15.78 ^{a} (18.66)	40.50 (15.38)	52.00 ^{a} (17.65)	51.05 (22.64)	52.37 (21.50)	48.16 (23.64)	50.26 (23.83)	8.49***	.83
Internal Task Unrelated (0-100%)	10.73 (13.38)	14.25 (17.86)	8.38 (7.88)	8.50 (8.64)	12.24 (11.75)	8.16 (8.49)	11.32 (12.78)	11.71 (10.80)	1.07	.39
External Task Unrelated (0-100%)	10.13 (8.75)	53.40 ^{a} (23.01)	15.13 ^{a} (12.63)	13.75 (18.15)	12.76 (16.22)	13.95 (18.36)	14.47 (20.94)	11.45 (13.73)	5.62**	.77
Heart Rate										
Heart Rate (bpm)	108.06 (13.24)	116.05 ^{a} (12.58)	113.00 ^{a} (11.50)	113.82 ^{a} (11.63)	112.89 ^{a} (16.09)	109.27 (13.58)	109.02 (12.13)	108.21 (14.28)	14.93***	.89
Change in Heart Rate (bpm)	-3.53 (6.61)	-5.37 (5.22)	-3.26 (8.66)	-3.39 (7.91)	-4.18 (6.40)	-1.64 (9.63)	-1.69 (8.24)	3.38 ^{a} (6.40)	4.31*	.70
Rate of Heart Rate Deceleration (bpm)	-26.46 (49.60)	-46.01 (44.77)	-39.13 (103.89)	-33.89 (79.13)	-50.11 (76.82)	-21.96 (128.46)	-16.88 (82.39)	45.06 ^{a} (85.39)	3.12*	.63

Table 5.2: Mean *(SD*) of each measure for control and experimental conditions. Note: ^{a} indicates significant difference from the control condition. ***$p < .001$, ** $p < .01$. * $p < .05$

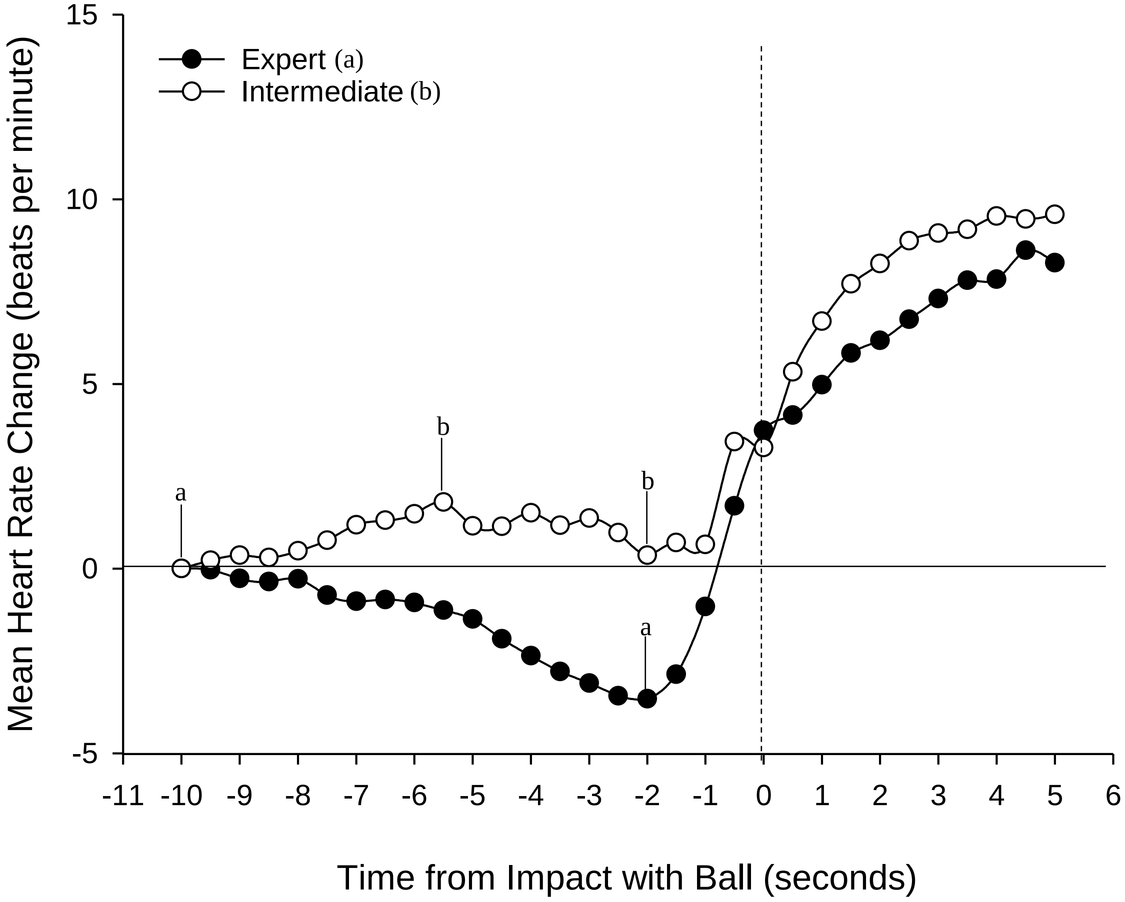
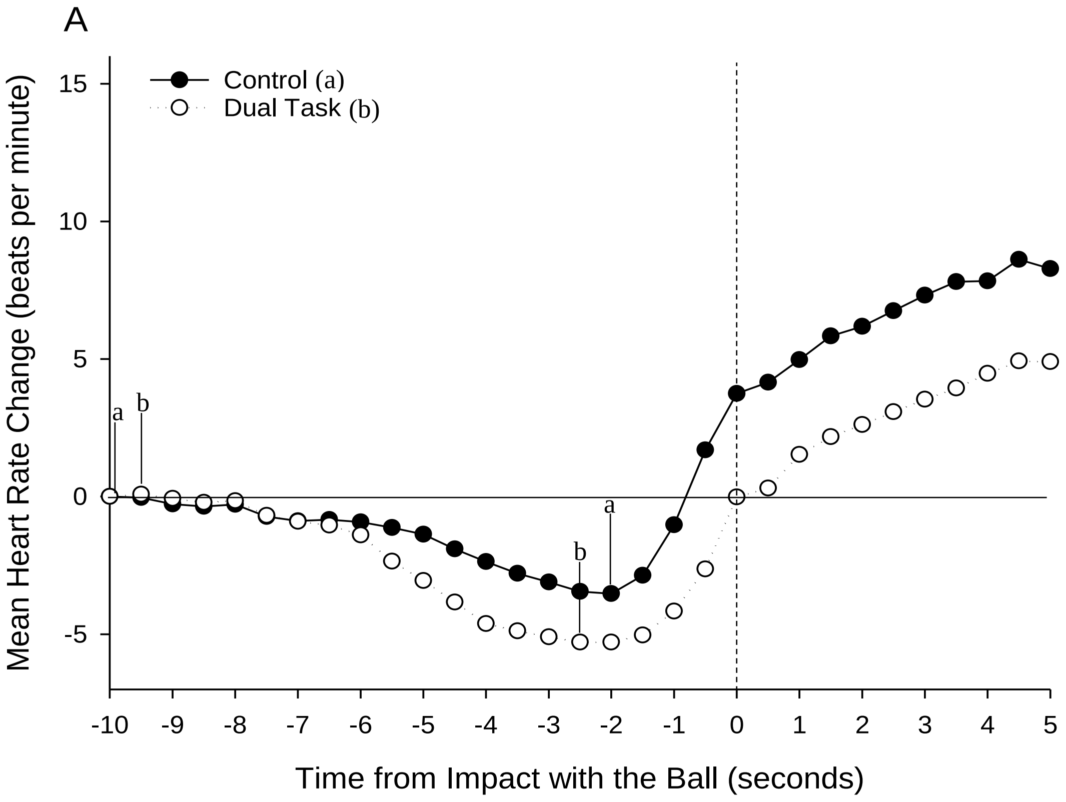
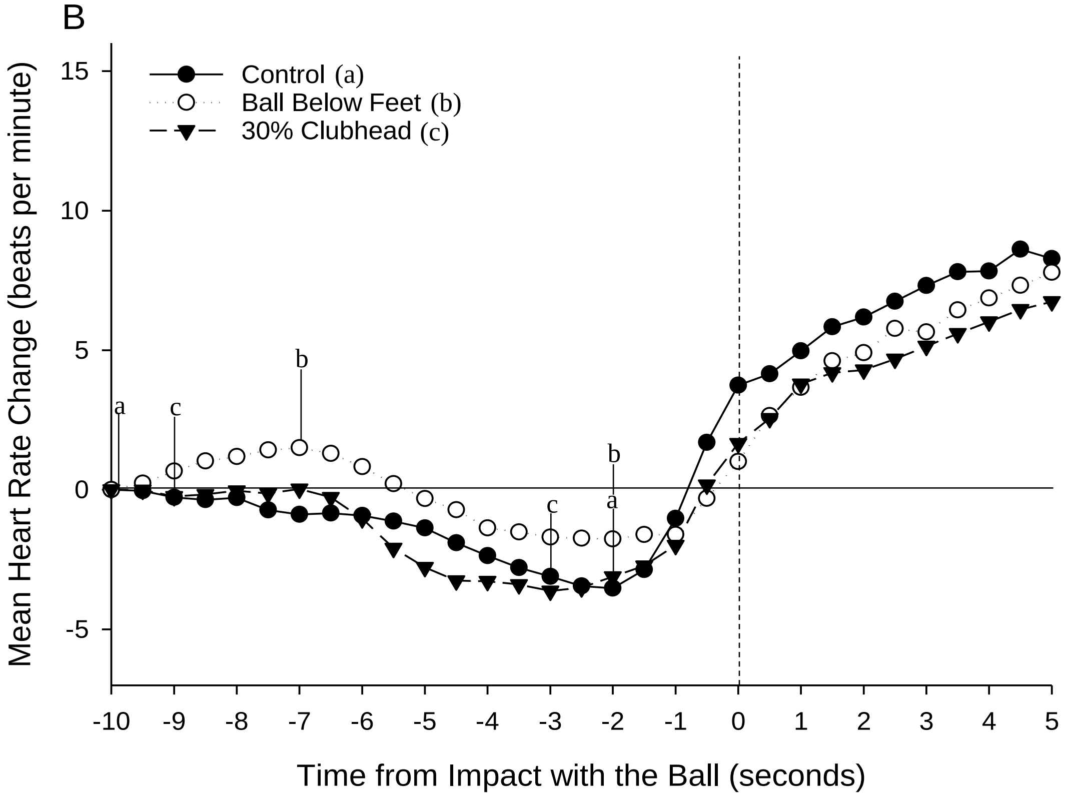


Figure 5.1: Cardiac deceleration under control conditions for expert and intermediate participants. Presented as the mean change in heart rate (HR) relative to 10 s before impact with ball for the 15 s recording period. [a, b] indicate the epochs where the lowest and highest pre-impact HR was recorded for each ability group. These timings represent the values used to calculate change in HR and the rate of HR deceleration.


A
Control (a)
Dual Task (b)
Mean Heart Rate Change (beats per minute)
15
10
5
0
-5
a
b
a
b
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time from Impact with the Ball (seconds)


B
Control (a)
Ball Below Feet (b)
30% Clubhead (c)
Mean Heart Rate Change (beats per minute)
15
10
5
0
-5
a
c
b
b
c
a
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time from Impact with the Ball (seconds)

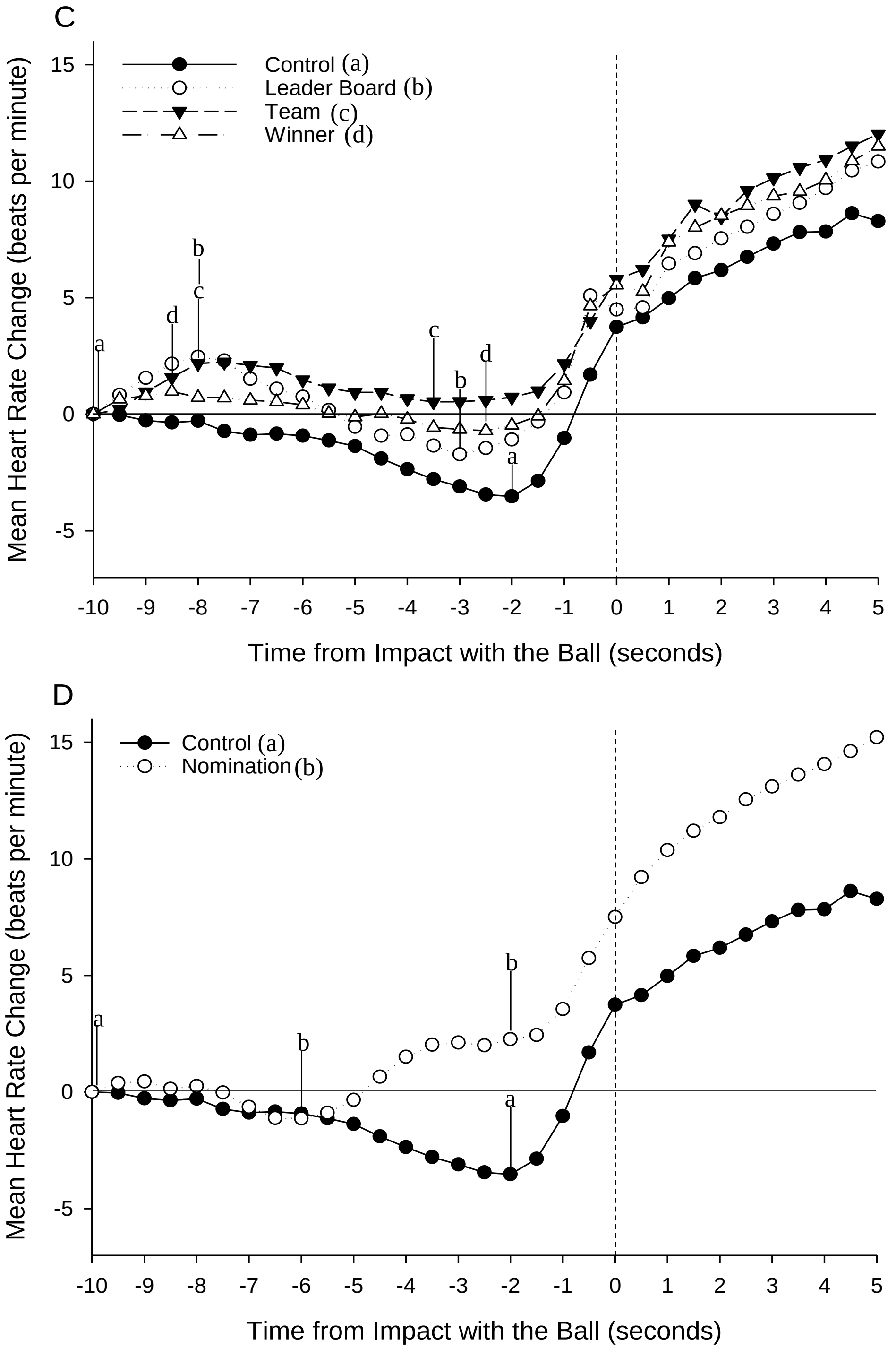


Figure 5.2: Mean heart rate (HR) change relative to 10 s before impact with the ball during a 15 s recording period for the control and experimental sub-theme conditions of (A) a dual task, (B) task difficulty, (C) pressure, and (D) single trial pressure. $^{a,\ b,\ c,\ d}$ indicate the epochs where the highest and lowest pre-performance HR was recorded in each condition. These timings represent the values used to calculate change in HR and the rate of HR deceleration.

Discussion

In extension of previous work (Boutcher & Zinsser, 1990; Neumann & Thomas, 2009, 2011), which intended to further explore the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980), the present study aimed to determine whether HR deceleration is exhibited in the seconds preceding intermediate and expert performance in a more physically demanding task. In line with the hypothesis, HR deceleration was exhibited in expert golfers prior to executing a full 8-iron golf shot, but unexpectedly no preparatory cardiac changes were observed for the intermediate group. Furthermore, under the premise that a secondary task, increased task difficulty, and exposure to pressure have the potential to alter attentional processes in a skilled motor task, psychophysiological methods were employed to explore expert performance. In contradiction of the hypothesis, performance was not affected by pressure or task difficulty, but was maintained in the presence of a dual task. As expected, the dual task condition limited internal focus of attention as a result of working memory being consumed, but internal focus unexpectedly also decreased in three out four pressure conditions compared to control. Whilst tonic HR rose in the dual task, task difficulty, and one pressure condition, preparatory bradycardia was only affected in the single trial pressure manipulation. These results are discussed below.

The Effect of Ability on Preparatory Cardiac Activity

First Phase: Deceleration

Results of this study indicate that only experts exhibited HR deceleration in the seconds before performing a more physically demanding skilled motor task, (i.e., full golf swing) than has been previously employed (Boutcher & Zinsser, 1990; Cooke *et al*., 2010; Neumann & Thomas, 2009). This is contradictory to previous findings in golf putting (a less physically demanding task), where despite significant differences in the magnitude of deceleration as a function of expertise, bradycardia has been observed in participants of all abilities (Boutcher & Zinsser, 1990; Neumann & Thomas, 2009). In support of the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980), these observations are in line with studies of attention which suggest that external focus is a characteristic of expertise (Fitts & Posner, 1967). Accordingly, experts in this study were likely to have been more effective at focusing on external cues and encoding information about the environment. Meanwhile, despite intermediates having been recruited for their ability to complete the task competently, the complex nature of a golf swing means they may still have employed features of declarative learning, such as, the explicit encoding of knowledge and the conscious programming/planning of movement (Fitts & Posner, 1967). Resultantly, the interpretation that intermediate participants did not exhibit HR deceleration because they may have been engaging in internal attentional processes, may be justified, and could offer further support for preparatory bradycardia being indicative of external focus of attention. However, no differences were seen between ability groups for any direction of attentional focus. As such, this perspective may be unsupported by the current findings.

Compared to previous findings where HR acceleration was noted prior to preparatory bradycardia in golf putting (Neumann & Thomas, 2009), no initial pre-performance acceleration phase was recorded prior to HR deceleration in the present study. In line with the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980), this previously witnessed acceleration phase is proposed to be indicative of performers initially focusing their attention on internal cues (Neumann & Thomas, 2009). With a full golf swing generally considered a more complex pattern of movement than golf putting, success is potentially associated with greater motor control programming and planning, particularly for lower skilled individuals. It is perhaps surprising therefore, that an initial acceleration phase was not observed. Whilst experts are commonly associated with external attention processes, which could explain the absence of initial HR acceleration in this case, recent work has shown that highly skilled athletes may be able to consciously modify movements during competition to maintain proficiency (Collins *et al*., 2001; Nyberg, 2015). Golf putting arguably requires finer motor control than a full golf swing, as the margins for error are generally smaller. Therefore, it could be that a full golf swing does not require the same initial period of internal focus, as small modifications to technical performance are not as impactful.

Second Phase: Acceleration

Similarly, the timing of the post-movement acceleration phase was found to be different in the current study compared to previous work in golf putting (Neumann & Thomas, 2009). Whilst pairwise comparison analysis indicated that acceleration started 0.5 s before and 0.5 s after impact with the ball (compared to HR at the baseline -10 s epoch) for intermediates and experts respectively, earlier research by Neumann and Thomas (2009) did not determine significant acceleration until 5 s after a putt had been struck. However, in the present research the lowest pre-shot HR was recorded at 2 s before impact with the ball for both abilities. Thus, looking beyond statistical significance, it could be deemed that acceleration actually began at this point.

With the movement of a golf swing thought to last around a second (Nesbit, 2005), this timing means it is unlikely that an increase in HR was due to metabolic demands initiating physiological reflexes associated with the onset of physical activity (see Horn & Swanson, 2013). The earlier acceleration seen in this study could instead be indicative of an anticipatory rise in HR. Previous work has shown that expert performers may be able to voluntarily adjust cardiac activity in preparation for completing tasks requiring explosive power (Benum *et al.,* 2021; McArdle *et al*., 1967). For example, Benum *et al.,* (2021) found that biathletes exhibited HR acceleration in anticipation of greater physical load before the beginning of a race and when approaching an uphill section of the course. Meanwhile, McArdle *et al*., (1967) determined that trained runners exhibited an accelerated HR immediately before performance in short distance compared to long distance events, and that the anticipatory HR increase represented 74% and 33% of total HR adjustment in each event respectively. This anticipatory model of voluntary HR control may add further support in favour of the intake-rejections hypothesis when considered in the context of this study. Despite an increase in HR potentially being expected as a result of the autonomic nervous system recognising the need for greater metabolic processes in anticipation of an explosive movement, HR deceleration was evident in experts. Therefore, compared to previous studies using low physically demanding tasks (e.g., Boutcher & Zinsser, 1990; Neumann & Thomas, 2009), it is more unlikely that preparatory bradycardia is a result of cardiovascular influences in preparation of a full golf swing. Moreover, because the two mechanistic processes may have been working in conflict, this notion may explain why the magnitude of bradycardia was not as great as previous golf putting studies (Cooke *et al*., 2014; Neumann & Thomas, 2009). In other words, HR was decreasing in response to external attentional focus, but a higher rate needed to be maintained in anticipation of action. As participants approached shot execution (i.e., a second before proposed movement initiation according to Nesbit, 2005), HR acceleration eventually became the predominant response to help address the imminent increase in metabolic demands. Whilst this physiological perspective may help implicate attentional processes with preparatory bradycardia, future work should measure both impact with the ball and movement onset to enhance analysis and interpretate findings in relation to the intake-rejection hypothesis.

However, given that anticipatory cardiac responses are mainly attributed to expert performance, this perception does not account for why intermediates exhibited the same acceleration pattern. Alternatively, in line with the intake-rejection hypothesis, the earlier pre-impact acceleration observed in the current study could be indicative of internal focus of attention. As a result of being in an earlier and more declarative stage of learning (Fitts & Posner, 1967), intermediate performers were likely exhibiting internal focus of attention. As previously mentioned, although automaticity is considered a feature of expertise (Anderson, 1982), recent research has proposed that conscious modification of movements in an attempt to maintain proficiency might be exhibited by experts (Collins *et al*., 2001; Nyberg, 2015). Hence, pre-impact acceleration in experts could also be suggestive of conscious control processes immediately prior to and during the golf swing. The argument that pre-impact acceleration is indicative of internal focus of attention, may therefore be substantiated across ability groups and could better link cardiac activity to the intake-rejection hypothesis.

Equally, internal focus of attention could have been unintentionally promoted in the current protocol, as the golf simulator set up meant participants were unable to clamp their cognitive system onto the environment (Glenberg *et al*., 1998). Shown by Carson *et al*., (2016), an increased state of intentional control is evident when attention-competing environmental information is depleted. In this study for instance, the lack of visual target and ball flight feedback may have encouraged greater internal focus of attention. Not only could this perception explain the acceleration phase seen immediately before impact with the ball in both ability groups, but it might also account for why intermediate participants did not exhibit any HR deceleration. In essence, both ability groups may have been affected by the environmental limitations, but attentional processes in experts may have been protected because they possessed an inherently greater level of automaticity. For example, Neumann and Thomas (2011) found that process goals aimed at provoking internal focus did not affect preparatory bradycardia, because some participants maintained external attentional processes due to engrained pre-performance routines. Thus, HR deceleration in response to external focus was possible during the majority of preparatory activity for expert participants, but not intermediates.

Whilst the additional physical demands of the current task cannot be ignored in terms of HR acceleration, the environmental effect on attentional control may also explain why no post-shot deceleration was observed in either group. Previous research in golf putting (Cooke *et al*., 2014) has found HR to remain at decelerated levels for a few seconds after shot execution as a result of participants processing external stimuli in order to employ environmental feedback to subsequent performances. With actual ball fight limited to a few metres (about 0.5 s until the ball hit the screen) then restricted to a virtual projection on screen (lasting around 5 s), post-shot external focus of attention was likely limited. To ecologically validate these findings and further explore potential psychophysiological implications, future work should extend the current study to a driving range or on course scenario.

The Potential for Physical Influences

The main opposing theory to the intake-rejection hypothesis, is the cardiac-somatic coupling and uncoupling theory (Obrist, 1968), which instead of attentional processes, implicates muscle quieting as the rationale underpinning HR deceleration. In support of this position, whilst no data were recorded in relation to pre-performance routines, both ability groups are likely to have addressed the ball in a stationary position prior to shot execution. The associated reduction in muscular and metabolic activity could account for HR deceleration in experts, but this argument is not relative for intermediate participants, as they did not exhibit bradycardia. Although electromyography data was not employed in the current study, this discrepancy could be reflective of less postural stability and/or increased muscle tension. Skill level has been shown to affect postural stability in sports like shooting where the effects of stability are similar to golf, in that it is a key determinant of success (Andreeva *et al*., 2020). Whilst increase muscle tension is associated with performance under pressure (Cooke *et al*., 2014). Intermediates reported feeling under more pressure than experts in the current study. Therefore, in line with the cardiac-somatic coupling and uncoupling theory, either postural instability or increased muscle tension could account for why intermediates did not exhibit preparatory bradycardia.

However, although no formal observations were made, as determined by Cotterill *et al*., (2010) it is likely that participants were engaging in a variety of movements such as practice swings, grip/stance adjustments, and viewing the shot as part of pre-performance routines. The occurrence of physical behaviours such as these during the preparatory phase, undermines the cardiac-somatic coupling and uncoupling theory, as physiological demands were likely to have been elevated in response to movement. Experts exhibiting pre-performance movement in the current study could also explain why the magnitude of bradycardia was observed to be less than preceding research in golf putting (Neumann & Thomas, 2009, 2011). In response to physical activity, the autonomic nervous system would normally initiate an increase in HR to address rising physiological demands (Horn & Swanson, 2013). Although pre-performance routines in golf putting are also likely to contain physical behaviours, the nature of associated movement rehearsal, means physiological influences might not be as significant on preparatory cardiac activity. Therefore, HR deceleration may not be as pronounced in the current work because cardiac activity concurrently reflected attentional processes and physiological reflexes linked to practice swings etc. Taken together, these findings suggest that physical pre-performance routine behaviours should be analysed in combination with psychophysiological measures to further explore whether attentional processes can be objectively measured through preparatory cardiac activity in skilled motor performance.

The Psychophysiological Effects of Experimental Manipulations on Experts

Performance

Apart from side spin, no significant changes in expert performance were observed. In contradiction of the hypothesis which predicted performance would be detrimentally affected by increased difficulty or pressure, performance remained consistent despite experimental manipulations altering the demands placed on participants. This null finding could be a result of task difficulty and pressure not being of a sufficient level to impact expert performance. For instance, Stoker *et al*., (2017) found that performance under pressure was only detrimentally affected if the task or environment were extensively manipulated. In this sense, the ball below feet condition may not have increased task difficulty enough to detrimentally affect performance, because experts would have been used to performing this task in competition. Similarly, whilst driver, fairway woods, and long iron shots are generally deemed to require a greater complexity of mechanics, a standard 8-iron shot is seen as a relatively straightforward performance element in golf (Diekfuss & Raisbeck, 2017). Despite asking participants to perform in the presence of additional demands, it could be that the 8-iron task was initially too simple for participants of expert ability to be affected. However, choking in sport is anecdotally synonymous with the simplest of tasks being performed poorly under pressure by elite athletes, which suggests that the amount and type of pressure applied in this study may not have been significant enough to induce a decline in performance. In support of this notion, Cooke *et al*., (2010) found that performance outcome only worsened in medium and high pressure scenarios compared to a low pressure condition.

Alternatively, processing efficiency theory (Eysenck & Calvo, 1992) could provide an explanation for the null findings in terms of pressure having a debilitative effect on performance in the current study. According to this model, performance can worsen as a result of pressure induced worry consuming attentional capacity to the extent where attentional processes integral to performance cannot be maintained. However, anxiety is thought to concurrently increase effort, which can equally enhance performance by increasing the amount of attention attributed to the task through activation of auxiliary processing resources. Where anxiety does not overwhelm auxiliary resources therefore, increased effort can positively impact performance. This perspective is pertinent for the current findings, as effort was only observed to increase in conditions where pressure was manipulated. As such, despite an increase in pressure in all four pressure conditions, performance may have remained consistent because increased effort meant performance efficiency could be maintained. This is similar to Wilson *et al.*, (2007) where increased effort was concluded to be the main factor contributing to performance effectiveness under pressure.

In contradiction of this position, participants also maintained performance in the 30% clubhead condition despite an increase in pressure. Performance consistency in this case could not however have been triggered via mechanisms associated with the processing efficiency theory, because effort did not increase. This discrepancy is instead potentially explained by the beneficial effects of external focus of attention (see Wulf, 2013). The attention pie chart revealed that whilst experts exhibited greater levels of focus on external task related factors (most likely the adapted club face), internal focus of attention on task related factors (such as joint position) decreased. As described by the constrained action hypothesis (Wulf *et al*., 2001), this synergistic increase and decrease in opposing attentional processes may have helped maintain performance through automaticity. Furthermore, an unexpected decrease in internal focus of attention in three out of four pressure conditions could have similarly helped experts perform consistently despite increased pressure.

Heart Rate

Physiologically, HR was found to increase in the dual task, leader board, and the two task difficulty conditions. The latter finding is indicative of previous work, which showed a main effect of difficulty level on HR (Carroll *et al*., 1986). Whilst pressure and task difficulty are generally regarded as separate entities, like pressure, more difficult task are likely to be accompanied by anxiety

(Tennyson & Woolley, 1971). Although only the 30% clubhead task difficulty condition was reported to elicit more pressure, it is possible that a greater tonic HR in both task difficulty conditions is reflective of participants feeling more anxious. Participants may not have recognised feeling more anxious in the ball below feet condition though, because expert golfers are likely to have regularly encountered an elevated stance in practice and competition due to the undulating terrain of golf course design, and as such, they did not perceive it as more difficult. This position is supported by participants rating the ball below feet and 30% clubhead conditions as 47% and 75% respectively more difficult than control. Likewise, participants also reported the dual task manipulation as more difficult, and therefore, a similar rationale may also explain increased HR in this condition. However, cardiac control processes may also be implicated in this case, as the protocol required participants to hit at least twice as many shots as all other conditions. Hitting a greater number of consecutive shots may have caused the autonomic nervous system to raise HR in response to an increase in metabolic demands (Horn & Swanson, 2013).

Meanwhile, an increased tonic HR in the leader board condition is probably physiologically reflective of increased anxiety, as anxiety almost always accompanies pressure in sport (Mullen *et al.*, 2005). However, from this perspective and in contradiction of the hypothesis, it is surprising that HR did not increase during the other pressure conditions. Due to the narrative involved in setting up the pressure conditions, counterbalancing was not possible. Therefore, all participants experienced the leader board condition first out of the four pressure conditions. Previous work has shown that participants can perform better under pressure after training with anxiety (Oudejans, 2008), suggesting that consecutive performances under pressure may gradually alleviate the effects of anxiety. As such, participants may not have exhibited greater HR in the subsequent pressure conditions because the manipulative effects were not as great. Alternatively, as the experts in the present study were recruited mainly from the university golf team, the leader board condition may have elicited a greater desire to perform as it presented an opportunity to win against their peers. As the desire to succeed is generally considered a main determinant of pressure (Beilock & Carr, 2001), perhaps the leader board condition was the only pressure scenario which encouraged psychological effects significant enough to activate physiological mechanisms associated with anxiety e.g., increased HR.

Phasic Bradycardia

Whilst these insights are valuable for the overall psychophysiological literature, the main aim of this study was to further explore phasic cardiac deceleration in relation to attentional processes. The two main measures used to analyse preparatory bradycardia indicated how fast and to what extent HR decelerated prior to shot execution. Although main effects were found within participants across conditions for change in HR and rate of HR deceleration, both measures only significantly differed from control in the nomination condition. In contrast to all other conditions where HR deceleration was observed, HR was found to accelerate around 3 bpm at a rate of 45 bpm between 6 s and 2 s before participants performed.

According to the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980), this acceleration is indicative of a reduced cortical response to external stimuli as a result of the reticular formation being restrained by promotion of the bulbar region (Brunia, 1993). Environmental cues may therefore not be as impactful in cases of HR acceleration (Hatfield *et al*., 1987), and internal focus of attention is instead likely to be the more prevalent attentional process. In the nomination condition, HR acceleration being reflective of increased internal focus of attention is concurrent with pressure research, which suggests that reinvesting explicit knowledge (Baumeister, 1984) or increasing conscious processing (Masters, 1992) can occur under pressure. However, these self-focus theories of choking imply that disruption of attention processes is accompanied by impaired performance. Performance remained consistent across conditions in the current study, and as such, mechanistic theories of choking cannot be linked to HR acceleration in the nomination condition. As previously discussed, a combination of low task difficultly and high skill level may have provided protection against impaired performance. Ultimately, internal focus of attention did not increase compared to control in the nomination condition, and therefore, the psychological data does not support the interpretation that HR acceleration is objectively indicative of internal focus of attention and potentially choking under pressure.

Inconsistencies in relation to the intake-rejection hypothesis are further observed in the 30% clubhead, ball below feet, and dual task conditions where HR deceleration was not affected despite an increase in external focus of attention. Whilst further work is required to understand how increased external focus of attention may influence the preparatory cardiac pattern, a null finding in conditions where external focus was found to increase somewhat undermines HR deceleration as an objective measure of attention. However, in both the 30% clubhead and ball below feet conditions an obvious change to the environment was made, and as such, perhaps participants placed more emphasis on external cues in self-report data as a result. It could be that an increase of external focus in both these conditions was not reflective of changes to attentional process, but was instead a subliminal experimental effect causing participants to mistakenly reflect that they had locked onto the environmental constraints. In support of this explanation, previous research (Carson *et al*., 2016) suggests that an increase in internal focus would contrastingly be expected in response to an elevated stance, as it is likely to encourage scrutiny of movement. Furthermore, when faced with a task involving novel features i.e., the 30% clubhead, experts are thought to generally assume an earlier stage of skill acquisition and revert to a more declarative style of skill execution involving greater conscious processing, and thus, internal focus of attention (Anderson, 1982). The dual task condition was effective in limiting internal focus of attention, however external task related focus was also impeded. Previous work exploring the intake-rejection hypothesis, has manipulated HR deceleration through the use of task relevant cues (Lacey & Lacey, 1970, 1974, 1980). Whilst external focus of attention was found to increase in the dual task condition, this was a result of task irrelevant factors. As such, perhaps no changes to HR deceleration were observed in conjunction with increased external focus because in order to produce manipulative results, the external focus must be relevant for task completion.

Performance Under Pressure

Although performance was maintained in comparison to control, it may also be valuable to reflect on why the nomination condition evoked the strongest physiological effect. The obvious difference lies in the methodology; the nomination condition was the only manipulation to employ a single-trial format. Whilst in most sporting contexts choking under pressure can normally be pinpointed to one action, researchers tend to collect and aggregate data over several trials to help enhance reliability and statistical power (Cooke *et al*., 2010, Stoker *et al*., 2017, 2019; Mesagno *et al*., 2011). A finding of HR acceleration in the nomination condition implies that a single trial methodology may be valuable in provoking processes synonymous with choking under pressure in a laboratory setting. Additionally, whilst no formal analysis was completed to look at individual differences in cardiac activity across conditions, a quarter of participants in this study conversely exhibited HR deceleration in the nomination condition rather than acceleration. In contradiction of Baumeister's (1984) position statement, overall, these results imply that not all pressures have equal effects, and that furthermore, individuals can react differently to different types of pressure.

Limitations and Future Directions

Use of multidisciplinary methods were a significant strength of the current study. However, there are limitations to consider which may hinder interpretation of the results. Firstly, a lack of electromyography restricts conclusions based on muscular influences. In challenge of the intake-rejection hypothesis, Obrist's (1968) cardiac-somatic coupling and uncoupling theory is difficult to rule out without clear indication that reduction of muscle activation does not accompany preparatory bradycardia. Similarly, whilst previous studies have indicated that respiration is not linked to HR deceleration in golf putting (Neumann & Thomas, 2009, 2011), future work should employ respiratory measures to discount the involvement of respiratory sinus arrythmia in phasic cardiac activity.

Secondly, expert performance was found to be more consistent than intermediate performance, but ball flight data remained unchanged within participants between conditions at an expert level. Many of the findings in this study would have been enhanced with changes to performance. Ball flight data is a valid coaching tool used to understand how the ball travels towards a target, and although a target was used in the pressure-based conditions to provide measurable feedback in line with the manipulative narrative, the lack of clear performance outcome measure across conditions may have hindered comparative interpretations. A target-based measure is therefore recommended for future studies of this kind.

Finally, this study was unable to fully test hypothesise at an individual level. As indicated by Bertollo *et al*., (2012) "*a group analysis of data with the aim of comparing novice vs. expert or worst vs. best performance outcomes i.e., performance based between individuals' methodology overlooks performance dynamics at the individual level*". Alternatively, multi-level modelling or probabilistic individual zones of optimal functioning (Bertollo *et al.,* 2012) analysis may provide a better method for investigating HR deceleration in relation to attention, as they are able to account for and embrace individual differences as part of the interpretive process.

Future work may wish to replicate the current study with these limitations in mind and expand findings to more ecologically valid scenarios, such as on the golf course during competition and using single trial data. More emphasis should also be placed on time locking linear and quadratic effects of the HR deceleration pattern to the physical and psychological pre-performance routine behaviours. Despite these current knowledge gaps, an expert-intermediate difference in preparatory bradycardia in a more physically demanding task was established in the present work and therefore continues to suggest the possibility of this phenomenon having beneficial properties in terms of skill acquisition and/or performance. Longitudinal studies aimed at training HR deceleration in novices may help to further highlight opportunities for competitive advantage.

Conclusion

In conclusion, this study confirmed the presence of HR deceleration in the second preceding shot execution in a more physically demanding task. In contrast to previous studies investigating movements requiring lower physical demands (Cooke *et al*., 2014; Neumann & Thomas 2009, 2011), the current work only detected bradycardia in expert and not intermediate golfers. Furthermore, no initial acceleration phase was seen in either group, but there was a clear increase in HR immediately prior to impact with the ball. Experts showed different psychophysiological responses when faced with a dual task, increased difficulty, and greater pressure. Whilst the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) was supported by some findings, certain conditions contradicted this theory. Individual differences and task design may account for inconsistencies. Having confirmed a relationship between HR deceleration and expertise, further research is warranted to determine the rationale for this well-established difference and how it may be used to inform optimal performance in future.

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CHAPTER SIX

General Discussion

The main aim of this thesis was to increase understanding of the psychophysiological processes associated with skilled motor performance. More specifically, how preparatory cardiac activity in the seconds preceding performance may be indicative of attentional processes. Under the premise that pressure, task difficulty, and secondary tasks may influence attentional focus, this body of work explores the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) in relation to sport performance. Furthermore, this set of experiments challenges the assumption that all pressures are equal (Baumeister, 1984). The purpose of this final chapter is to summarise the findings of each empirical chapter and propose how the outcomes contribute to the psychophysiological literature. The novelty of these conclusions and potential implications are discussed in the context of theory, practice, potential limitations, and future directions.

A Summary of Aims and Findings

Chapter two sought to explore the psychophysiological responses to isolated pressure manipulations in novice golf putting. Previous research has typically adopted the historical position that pressure, regardless of origin, evokes equal effects on performance (Baumeister, 1984). Given the potentially debilitative performance implications of increased self-focus as a result of heightened pressure (Baumeister, 1984; Masters, 1992), results were considered relative to performance and self-reported conscious processing. Overall, chapter two found variation across experimental conditions which contradicts Baumeister's (1984) position. Within consequence-based pressure conditions, the main evaluative manipulation caused performance outcome to worsen compared to control, but improvement effects on performance accuracy were observed in three of the other four consequence-based pressure conditions. In comparison, conditions where task demands (i.e., time pressure, and increased task difficulty) were manipulated, performance outcome and accuracy were found to worsen with increased pressure and conscious processing. In combination, the results from chapter two imply that not all pressures create equal effects. Dependant on whether the pressure is consequence- or demand-based, different effects are observed in the various processes implicated with successful skilled motor performance. Generally, demand-based pressures evoke the greatest harmful effects on performance in a laboratory setting.

Adopting the perspective that task demands alter performance processes, chapter three assessed how the well-established pattern of preparatory bradycardia (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Cotterill & Collins, 2005; Neumann & Thomas, 2009, 2011) may vary as a function of task difficulty in expert golf putting. The intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) describes the relationship between heart rate (HR) deceleration in seconds before skilled motor performance and external focus of attention. External focus of attention has been linked to expertise and optimised performance (see Wulf, 2013), and as such, is believed to be beneficial for skilled motor execution. Experts have been shown to exhibit greater HR deceleration prior to performance than novices (Neumann & Thomas, 2009), and as experts are generally considered to exhibit external attentional focus during preparation for action (Fitts & Posner, 1967), greater bradycardia logically supports the intake-rejection hypothesis. Under the premise that increased task difficulty may affect attentional processes and that HR deceleration could be indicative of attentional focus, it was therefore hypothesised that the magnitude of bradycardia would increase in response to more difficult tasks. Whilst the pattern of preparatory cardiac activity was affected by task difficulty, contrary to the hypothesis, condition had the largest effect on the rate of HR deceleration. This cardiac measure also proved to be the most significant correlate of performance. Performance was generally found to be better and worse in easier and more difficult conditions, respectively. The rate of HR deceleration increased in easier conditions, and thus corresponded to improved performance. In sum, chapter three adds further support for preparatory bradycardia as an objective measure of attentional focus. Whilst the magnitude of HR deceleration may be related to expertise, the results of this study suggest that the rate of HR deceleration may be indicative of attentional efficiency, which furthermore could be key for performance.

Using a combination of protocols from chapters two and three, chapter four extended findings to a large novice cohort executing a different skilled motor task, dart throwing. Moreover, a dual task condition was introduced to help further explore the relationship between psychophysiological measures and attentional processes. Given that an increase in internal focus of attention has been linked to poor performance (Hardy *et al*., 1996; Lohse *et al*., 2010; Maddox *et al*., 1999; Wulf, 2013), the secondary task was expected to have a protective effect, as participants would be unable to exhibit disruptive attentional processes due to working memory being consumed. A new measure of attentional focus was also created for this study. The attention 'pie chart' extends previous measures, as not only does it indicate the extent of change in attentional focus, but it also helps to describe the direction of change i.e., if one type of attentional focus decreases, does another type of attentional focus become more prevalent. Although the extent of preparatory bradycardia was found to be lower than chapter three and previous research (Cooke *et al*., 2014; Neumann & Thomas, 2009), a pattern of HR deceleration in a different context was nonetheless demonstrated. As predicted, the dual task manipulation had no effect on performance, but unexpectedly, it caused participants to exhibit a greater rate of HR deceleration compared to control. As indicated above, the dual task condition meant participants did not have an opportunity to engage in internal focus of attention, so whilst HR deceleration was not more pronounced, it was proposed to be more efficient. The ability to prepare for action more efficiently is another key characteristic of expertise (Fitts & Posner, 1967), and thus, implies that a quicker rate of deceleration could be beneficial for performance. In replication of chapter three, performance worsened in more difficult tasks and improved in easier tasks, but conversely, no changes in preparatory cardiac activity were found. Pressure was confirmed to increase in all conditions, but performance improved in 75% of the competition conditions compared to control. Again, no changes to the HR deceleration profile were observed for the pressure-based conditions. However, the single trial pressure manipulation caused nearly a four-fold increase in variability associated with the rate of HR deceleration. Furthermore, the lowest point of HR deceleration was exhibited 3.5 s earlier in the single trial condition compared to control, suggesting that the winner condition may have affected cardiac activity in some participants. In conclusion, findings associated with the dual task condition add further support in favour of the intake-rejection hypothesis. However, pressure and task difficulty conditions did not yield significant physiological results. The novice cohort may have limited findings in this sense, as a typically smaller magnitude of HR deceleration may have been less susceptible to influential factors. Moreover, disruptive effects of pressure and task difficulty on attentional processes (e.g., increased conscious processing) may have been less apparent, because declarative execution of skill meant internal focus was predominantly exhibited. Nonetheless, increased variability and differences in timing of the HR deceleration pattern in the single trial pressure condition, indicate that further research using these protocols is warranted.

The final empirical chapter aimed to expand the principles discussed in the previous three studies to a more physically demanding and novel skilled motor task, a full golf swing. The main opposing theory to the intake-rejection hypothesis suggests that the HR deceleration phenomenon is indicative of muscle and metabolic quieting (Obrist, 1968). With more physically demanding tasks generally corresponding to increased HR either in anticipation of (Benum *et al*., 2021) or in immediate response to (Horn & Swanson, 2013) greater metabolic demands, the confirmation of preparatory bradycardia in the seconds before a full golf swing was proposed to help further substantiate the intake-rejection hypothesis. In contrast to previous golf putting studies (Neumann & Thomas, 2011), HR deceleration was observed in experts but not intermediate golfers. The magnitude of bradycardia was less than previous findings (Cooke *et al*., 2014; Neumann & Thomas, 2011) but significant in experts, nonetheless. The concept of condition sub-themes (dual task, task difficulty, and pressure) were replicated from chapter four but applied so manipulations were relevant for a golf scenario. Performance remained consistent in experts across conditions - a finding which was mainly considered to be reflective of the underlying task simplicity. Whilst tonic HR increased in response to the dual task, task difficulty, and one competition condition, the HR deceleration pattern was only found to differ in the single trial pressure condition. In contrast to all other manipulations, HR acceleration was the primary cardiac response preceding performance in the condition which depended on a one-off shot. Chapter five discusses how these results further understanding of the relationship between attentional processes and preparatory bradycardia. Although aggregate data offers statistical power in terms of empirical analysis, the single trial methodology presented in the chapter five suggests that protocols which better resemble ecological performance may provide greater psychophysiological insight for pressure related hypothesise.

In conclusion, the four empirical chapters presented in this thesis challenge the longstanding assumption that all pressures are equal (Baumeister, 1984) and add further support for the intake-rejection hypothesis. More specifically, HR deceleration has been replicated in two different contexts and confirmed in one novel task. The novel full golf swing was also a more physically demanding task than previously explored within the literature. The HR deceleration profile was affected by a dual task, task difficulty, and pressure manipulations. Whilst the magnitude of the bradycardia appears to remain the main characteristic of expertise in terms of this phenomenon, the rate of HR deceleration proved the best correlate of performance and may inform a novel model of attention efficiency. Finally, the greatest psychophysiological effects of pressure were observed as part of the single trial protocols, suggesting that isolated ecological performance scenarios may prove insightful.

Theoretical Implications

Performance Under Pressure

Given Baumeister and Showers (1986) broad and situational definition of performance that "*an individual can be termed as 'performing' whenever they carry out a task in a situation which requires an optimal outcome*", it is widely accepted that increased pressure can detrimentally affect performance (Hill *et al*., 2010) in individuals of any ability. Previous work has found evidence for performance worsening in table tennis (Williams *et al*., 2002), driving (Wilson *et al*., 2006), and handgun shooting (Oudejans, 2008). In contrast, whilst controversy remains on whether competition inhibits or enhances performance, Stanne *et al*., (1999) concluded that competition encourages better motor performance than individualistic scenarios. Ego-threat may impact performance though when athletes are faced with an individualistic scenario that will directly affect team-mates (Baumeister, 1997). In terms of pressure research, competition is rooted in consequential themes of evaluation, punishment, and/or reward. Ultimately, under the assumption that pressure has equal effects (Baumeister, 1984), regardless of the origin and psychological mechanisms leading to an impact on performance, many experimental protocols with similar conclusions have employed different pressure manipulations.

Whilst recent studies have begun to challenge this position (Mesgano *et al*., 2011; Stoker *et al*., 2017, 2019), ease of application and suitability for research hypotheses (e.g., Mesagno *et al*., 2011 selected video recording to explore self-presentation and choking, for its ability to heighten self-consciousness) generally remain the overwhelming rationale underpinning methodological design. Although the selection of a pressure manipulation is not often extensively discussed in the context of empirical findings, a mounting body of evidence suggests the type of pressure employed may have important implications. For instance, using a variety of evaluation and monetary reward manipulations, Mesagno *et al*., (2011) found performance in a field hockey task declined in groups that were exposed to themes of self-presentation. However, performance conversely improved in the performance-contingent monetary incentive and video-camera placebo groups. Similarly, although consequences were required to induce pressure, Stoker *et al*., (2019) contrastingly found performance to improve in a forfeit condition compared to when cognitive fatigue was manipulated by a pre-performance Stroop colour-word test. Stoker *et al*., (2017) observed perceived pressure to be greater in consequence-based pressures (e.g., evaluation, reward, and forfeit) than control conditions, but performance only worsened when task or environment manipulations were simultaneously applied (e.g., occlusion goggles, time constraint, and noise distraction). From a psychophysiological perspective, Stoker *et al*., (2017) also found that consequence-based pressures evoked a higher HR than control, but no change in HR was observed in conditions where pressure was induced by manipulating the task (e.g., target size, distance from target, and random versus block task completion).

This body of work is extended by the findings presented in this thesis. Chapters two, four, and five provide further evidence that distinct pressure manipulations may evoke varied psychophysiological responses. For instance, these chapters determined that although pressure generally increased in experimental conditions as expected, findings relating to performance were inconsistent. In agreement with Stoker *et al*., (2017), performance worsened in conditions where pressure was induced by manipulating the demands of the task (i.e., more difficult or time constraint), and mirroring findings by Mesagno *et al*., (2011) where evaluation and self-presentation was greatest. However, performance improved in conditions with a competitive element and/or performance-contingent monetary reward. This is broadly in line with Stanne *et al*.'s (1999) meta-analysis of the effects of competition, where performance was deemed to be better in team sports than individualistic scenarios. However, this thesis also found individualistic competition to evoke increased accuracy compared to control. The only outlier in these observations is chapter five, where performance remained consistent despite manipulating the demands of the task and the performer. As discussed within the chapter, the performance measure in this study was a limiting factor in that it did not provide a singular metric of performance outcome. However, consistency of movement is a characteristic of expertise (Fitts & Posner, 1967), and this discrepancy between chapters could be explained by the participants used in chapter five being the most skilled in comparison to other samples in this thesis. Moreover, the task used in chapter five may have been too simple for experts to have been affected by conditions.

Whilst an increase in HR has been linked to pressure induced anxiety (Åstrand *et al*., 2003), and thus, is assumed to be a correlate of poor performance under pressure (Cooke *et al*., 2010; Mace & Carroll, 1985; Mace *et al*., 1986; Oudejans & Pijpers 2009, 2010; Stoker *et al*., 2019), chapter two conversely only observed HR to increase in conditions where performance improved. In chapter four however, a decrease in HR was observed in all the task difficulty conditions and one of the competitive conditions despite discrepancies in performance results. This is in contrast to previous work which suggests an expected rise in HR, as an increase in task difficulty has been shown to evoke anxiety (Carroll *et al*., 1986). Although links with performance were also unclear in chapters four and five, HR increased relative to control in the single trial pressure manipulation in chapter four, and the dual task, the first pressure, and both task difficulty conditions in chapter five.

While this thesis presents some similarities across studies in terms of the different psychophysiological effects pressure can have on performance, more research is required in this area to fully understand the implications of applying certain types of pressure manipulations as part of experimental methodologies. Ultimately, the inconsistencies highlight the importance of considering results that explore performance under pressure in contradiction of Baumeister's (1984) venerable assumption that all pressures are equal. In combination, the empirical chapters presented in this thesis allow Baumeister's (1984) position statement on pressure to be reconsidered, and suggest that future work should design methodology with the potential differing effects of isolated pressure manipulations in mind.

In addition to this reconsidered perspective, previous research has mostly relied on multiple trial data to explore performance under pressure (Cooke *et al*., 2010; Oudejans, 2008; Williams *et al*., 2002; Wilson *et al*., 2006). Whilst incidences of choking can occur over extended performances (e.g., an entire match), ecological occurrences of pressure having a detrimental effect on performance can often be pinpointed to isolated moments/actions. For instance, the England Men's senior football team have been historically linked to choking under pressure during penalty shoot outs in major tournaments. Victory in this scenario is reliant on one successful shot from each player. However, to validate findings through statistical power, laboratory manipulations generally focus on aggregated data methodology. Furthermore, it is a recognised limitation in performance research, that it is difficult to expose participants to pressure equal to that of competitive sports performance (Baumeister & Showers, 1986). Whilst studies have attempted to compensate for this challenge by endeavouring to employ varying levels of pressure (Cooke *et al*., 2010; Worthy *et al*., 2009) and sudden death protocols (Vine *et al*., 2013), performance findings can be inconsistent.

This thesis is no different in this regard, where contrary to the choking literature, performance mostly did not suffer with increased pressure. However, psychophysiological findings suggest that participants were experiencing interference. Although the relationship was not consistent and/or linear, the single trial pressure manipulations introduced in chapters four and five appeared to elicit the largest effects on psychophysiological measures. Participants reported feeling under most pressure and exhibited the greatest levels of effort in the single trial conditions compared to control. Moreover, instead of typical HR deceleration, acceleration was found to be the prominent preparatory cardiac activity in the single trial pressure manipulation in chapter five. Whilst no statistical differences were observed in the equivalent condition in chapter four, variability in HR measures was greatest in the one-throw condition. This highlights another noteworthy discussion point within this thesis, that individuals may respond differently to different types of pressure.

Previous work has explored whether individuals have a predisposition to exhibit reinvestment under pressure (Masters *et al*., 1993), and whether personality traits can predict performance in pressurised scenarios (Byrne *et al*., 2015). Moreover, as described by Bertollo *et al*., (2012) "*a group analysis of data with the aim of comparing novice vs. expert or worst vs. best performance outcomes i.e., performance based between individuals' methodology overlooks performance dynamics at the individual level*". This thesis provides further tentative evidence that some significant results may be overlooked when analysing data at a group level.

Despite these observations, performance did not worsen in the single trial pressure manipulations, and thus, casts doubt over whether this manipulation format could help to further our understanding of choking. Chapters four and five discuss why effects might not have been seen despite psychophysiological measures being disrupted. Protective processes such as the processing efficiency theory (Eysenck & Calvo, 1992), maintenance of beneficial attentional processes (Baumeister, 1984; Masters, 1992), and level of expertise (Fitts & Posner, 1967) are all offered as potential mechanisms.

In sum, this thesis indicates that single trial pressure manipulations may be more insightful for psychophysiological research, especially when aims are associated with choking under pressure, as effects are potentially greater than aggregated methodology. Additionally, analysing results from a more individualistic perspective could assist in identifying novel and more impactful findings.

The Intake-Rejection Hypothesis

The intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) describes the psychophysiological relationship between preparatory bradycardia in the seconds preceding skilled motor performance and attentional processes. It proposes that HR deceleration increases the flow of environmental information to the brain by unloading the baroceptors through a reduction in blood pressure (Brunia, 1993). An increase in HR is contrastingly suggested to reduce the cortical response to external stimuli by causing a promotion of the bulbar restraint upon the reticular formation. Thus, where HR acceleration is detected this visceral afferent feedback model suggests environmental cues are not as impactful (Hatfield *et al*., 1987). In essence, HR deceleration is thought to be an objective measure of external focus, whilst HR acceleration may indicate internal focus. Support for this theory has been offered through reaction time paradigms (Lacey & Lacey, 1970, 1974, 1980) and sports performance studies (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009). Whilst links to performance remain somewhat illusive, HR deceleration has been established as a function of expertise with more skilled individuals exhibiting a greater magnitude of bradycardia.

This thesis sought to extend these findings using dual task, task difficulty, and pressure methodology. Under the premise that manipulations associated with these themes could disrupt attentional processes, chapters three, four, and five examined HR deceleration relative to performance. HR deceleration was confirmed in all three relevant chapters. Chapter three replicated previous findings in golf putting (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009), whilst chapter four used dart throwing, and chapter five employed a novel task; a full golf shot. The magnitude of HR deceleration in the latter two chapters was smaller compared to chapter three and previous work. This discrepancy is discussed within the thesis in the context of expertise, physical demands, and complexity of task. In addition to previous literature, chapter five also established an expert versus intermediate difference in preparatory bradycardia in a more physically demanding task. Whilst chapter four and existing work (Neumann & Thomas, 2009) has found HR deceleration in less skilled populations, no bradycardia was exhibited by intermediate golfers in chapter five. This was contrary to the hypothesis and was explained by the complexity of task demanding elements of declarative learning, such as, the explicit encoding of knowledge and the conscious programming/planning of movement (Fitts & Posner, 1967). Taken together, the presence of HR deceleration in three chapters of this thesis help to further substantiate the intake-rejection hypothesis because logical inferences can be made in terms of optimal attentional processes for skilled motor performance and characteristics of expertise.

The introduction of a dual task in chapters four and five was designed to consume working memory, and therefore limit the ability of participants to engage in potentially harmful attentional processes, such as conscious processing (Master, 1992). In line with the intake-rejection hypothesis, HR deceleration was anticipated to remain similar to control when a secondary task was employed, as it would encourage automaticity. Chapter five confirmed this hypothesis, whilst chapter four yielded a greater rate of HR deceleration in response to the dual task condition compared to control. The difference in results across thesis chapters may be associated with expertise. Participants were novice and expert in chapters four and five respectively. According to skill acquisition literature (Fitts & Posner, 1967), performance becomes more automatic and unconscious with the development of expertise (Anderson, 1982). As such, the dual task condition may not have evoked a different pre-performance cardiac pattern in chapter five, because participants were already optimally engaging in external focus of attention under control conditions. In chapter four, however, the rate of HR deceleration may have increased relative to control because the completion of a secondary task limited internal focus of attention, which novices were likely exhibiting under control conditions. Given the underlying mechanistic rationale of these observations, this thesis therefore adds further support in favour of the intake-rejection hypothesis in the context of performance with a secondary task. To strengthen the impact of this theoretical implication, future work should replicate this methodology under pressure, when attentional processes have greater potential to be disrupted. Essentially, if HR deceleration is affected by increased pressure but maintained when a dual task is completed in a pressurised scenario, then the skill acquisition narrative suggests that preparatory bradycardia is likely to be indicative of external focus of attention.

Pressure is equally implicated in the disruption of attentional processes, with self-focus theories of choking (Baumeister, 1984; Master, 1992) synonymous with increased levels of internal focus. Concurrent with the intake-rejection hypothesis, chapters four and five used a series of isolated pressure manipulations to test whether HR deceleration might be affected as a result of increased pressure causing participants to reinvest explicit knowledge. Despite pressure rising in all relevant manipulations in chapter four, no changes to the HR deceleration pattern were observed. Similarly, three out of four pressure conditions in chapter five likewise failed to affect any features of cardiac activity. However, in the single trial pressure manipulation, expert participants were found to exhibit HR acceleration. Performance did not change in chapter five but was unexpectedly found to improve relevant to control in 75% of the pressure conditions in chapter four. These differences are discussed in the context of pressure literature within chapters four and five. More specifically, how competition has been shown to improve performance (Stanne *et al*., 1999), how bradycardia may have been less susceptible to interference due to a smaller magnitude than previous work, and why the single trial manipulation may have been the only pressure condition to cause significant effects. Whilst the use of pressure in this thesis may not have greatly further substantiated the intake-rejection hypothesis, the fact that HR acceleration was observed in the nomination condition in chapter five, suggests pre-performance cardiac activity can be affected by pressure. Thus, given the implication of attentional processes in the breakdown of performance under pressure, HR deceleration may objectively indicate external focus of attention. With the challenges of inducing pressure in a laboratory setting already discussed in the present chapter, future work should extend these principles to a more applied scenario e.g., competitive performance on course in golf. Considering the narrative surrounding the relationship between attention and performance under pressure, this type of work could help ascertain what effects pressure may have on HR deceleration, and hence, further our understanding of the intake-rejection hypothesis.

Task difficulty perhaps produced the largest effects on preparatory bradycardia in the current thesis. Under the premise that attentional focus is likely to be greater in more difficult tasks, in further support of the intake-rejection hypothesis, I proposed that HR deceleration would increase in conditions where tasks were designed to be more difficult. Whereas no changes were seen in chapters four or five, chapter three generated significant effects on the HR deceleration pattern. A null finding in chapters four and five was considered in relation to processing efficiency theory, attentional focus requirements, and the general psychophysiological effects of anxiety. Contrary to my hypothesis, chapter three found that although the magnitude of bradycardia did vary as a function of task difficulty, the rate of HR deceleration proved to be a stronger correlate of performance. The rate of HR deceleration was faster in easier tasks where participants performed best, and slower in more difficult tasks where participants performed worst. Practically, this meant that HR deceleration started earlier and took longer to reach the lowest point in more difficult tasks. This thesis agrees with previous literature which has used expert novice difference to demonstrate the intake-rejection hypothesis (Boutcher & Zinsser, 1990; Cooke *et al*., 2014; Neumann & Thomas, 2009), in that greater HR deceleration may be feature of expertise, and thus, indicative of external focus of attention. However, contrary to the notion that the extent of preparatory bradycardia may therefore be influential on performance, this thesis suggests that the rate of HR deceleration could be more important for success.

Similar to Tremayne and Barry (2001), chapter three discussed this finding in terms of attention efficiency. Interpreting the results in this way, a slower rate of HR deceleration could be indicative of participants exhibiting greater engagement with the task, and therefore being more efficient in narrowing attentional focus to enhance additional planning and programming processes associated with greater task difficulty. Alternatively, the lengthier HR deceleration profile could represent the more difficult tasks evoking a mixture of internal and external attentional processes, with the slower rate of HR deceleration being indicative of participants requiring longer to reach optimal levels of pre-performance automaticity. Given the narrative underpinning the relationship between external focus of attention and expertise (see Fitts & Posner, 1967; Wulf, 2013), this interpretation could help further our understanding of the intake-rejection hypothesis. Ultimately, this thesis presents the motion that whilst experts may be able to manipulate attentional focus to optimally meet the demands of the tasks, HR deceleration can only be acquired through the development of expertise. As such, I propose the following model associated with the intake-rejection hypothesis; phasic preparatory bradycardia is indicative of attentional processes through the mechanisms described by Lacey and Lacey (1970, 1974, 1980). However, the magnitude of HR deceleration can only be increased through skill acquisition and fundamental adoption of optimal attentional processes. As indicated by the rate of HR deceleration measure though, experienced athletes may have the ability to adapt attentional processes in response to differing levels of environmental cue processing being necessary for successful task completion.

Previous work looking at the idea of developing attention efficiency through maturation (Rueda *et al*., 2015), suggests that efficiency may be a learned neurocognitive process. Furthermore, whilst conscious control is generally thought to impede performance, recent research has shown that elite athletes may be able to consciously modify movements during competition to maintain proficiency (Collins *et al*., 2001; Nyberg, 2015). As described by Toner and Moran (2014), the ability to flexibly allocate attention dependant on context-specific demands, appears possible in a competitive performance (Bernier *et al*., 2011) or an injury recovery scenario (Collins *et al*., 1999). Moreover, efficiency in terms of switching between attentional processes, is implicated in continuous improvement and the pursuit of elite status through deliberate practice (Toner & Moran, 2015). In combination, the findings presented in this thesis offer further support for phasic bradycardia in the seconds preceding skilled motor performance as an objective measure of attentional processes. However, attentional efficiency, as indicated by the rate of HR deceleration, could be more important for expert performance.

Attentional Processes

Attentional processes have long been associated with successful sports performance. There is a mounting body of research in favour of external focus of attention facilitating accelerated learning and more robust performance (Hardy *et al*., 1996; Lohse *et al*., 2010; Maddox *et al*., 1999; Wulf, 2013). In response to this position, Wulf and colleagues have conceptualised the constrained action hypothesis (McNevin *et al.*, 2003; Wulf *et al*., 2001). This model suggests that external focus of attention enables automatic control mechanisms to run without interference. Meanwhile, internal focus of attention encourages conscious control, and thus, inhibits automatic control mechanisms. Similarly, reinvestment (Baumeister, 1984) and conscious processing (Masters, 1992) are two main theories implicated with the breakdown of skill under pressure, which are both synonymous with internal focus of attention. Given that attentional focus is an explicit feature of the intake-rejection hypothesis and performance under pressure, this thesis sought to measure attentional processes as part of a concurrent psychophysiology methodology.

The first two empirical chapters employed Cooke's *et al*., (2011) putting specific conscious processing scale, whilst the latter two chapters introduced a novel attention pie chart. Inconsistencies were observed in chapter two relative to the conscious processing literature. For instance, increased conscious processing could only be attributed to poor performance in a quarter of conditions in chapter two. Whereas participants reported increased conscious processing in half of conditions where performance worsened in chapter three. However, in line with the consciousness processing hypothesis (Masters, 1992) which suggests increased self-focus may impair performance, a decrease in conscious processing was recorded in the only condition where performance improved across the two chapters (50 cm condition in chapter three). These results are inconsistent compared to the aims of this thesis, where an increase in conscious processing was anticipated to have detrimental effects on performance. These results are discussed in relation to the intake-rejection hypothesis, performance under pressure, and control of movement. In terms of theoretical implications, this thesis suggests that performance may not always decline in response to increased conscious processing, and similarly, performance can worsen without individuals engaging in greater levels of conscious processing. Future work should look to explain what protective mechanisms performers employ to help maintain performance when conscious planning and programming are required for task success, and where conscious process does not increase, what other processes evoke a breakdown of skill.

Whilst the putting specific conscious processing scale (Cooke *et al*., 2011) captures conscious control, and therefore internal focus of attention, it is somewhat one-dimensional in its conclusions. For instance, information is provided regarding whether an individual is exhibiting increased or decreased levels of conscious processing, but it does not help interpretate which alternative attentional process may have been compromised or become more dominant as a result. The attention pie chart introduced in chapters four and five was designed to overcome this limitation. The dual task manipulation in both chapters which utilised this measure, provides the best example of its potential. The attention pie chart helped to identify that the predominant point of focus was external task unrelated factors (i.e., response prompts) in the two dual task conditions. Furthermore, I was able to infer that greater focus was achieved in this area because participants were exhibiting less internal and external focus on task related factors compared to control. A similarly synergistic observation was made in one of the task difficulty conditions in chapter five, where participants reported a decrease in internal focus and an increase in external focus relating to the task. As discussed within chapters four and five, these findings are in line with attention research which suggests that external focus of attention may increase in more difficult tasks and asking participants to complete a secondary task will help prevent the accumulation of internal attentional processes. However, no links to performance were made with these cooperative examples. So, whilst this thesis presents a novel measure for directionally evaluating self-report attentional focus, further work is required to validate it in the context of performance.

Practical Implications

Experimental Methodology

As discussed in the narrative above, this thesis presents several implications in terms of experimental methodology. Firstly, the application of pressure in performance research should be considered in terms of individualistic effects, rather than working under the historical assumption that all pressures are equal (Baumeister, 1984). Secondly, single trial pressure manipulations can affect performance and psychophysiological measures and may provide further insights above and beyond traditional aggregate, and/or additive pressure manipulations. To help unequivocally bridge the gap between theory and practice though, future studies should consider how to apply psychophysiological methods to more ecological scenarios i.e., transferring laboratory findings to ‘real world’ sports performance. Thirdly, in terms of measures to help further understand performance from a psychophysiological perspective, the rate of HR deceleration metric and attention pie chart self-report measure should prove valuable. Finally, this thesis suggests that this area of research should be extended to include novel skilled motor tasks, including more physically demanding movements which have been previously dismissed on account of potential physiologically limiting factors. Adopting a gradually more applied outlook to performance research in this sort of way, will help impact outside of academia become increasingly effective.

Skilled Performance

Skilled sports performance is multifactorial. This thesis adds to the applied understanding of how psychophysiology can provide a unique insight into concurrent processes, such as attention and cardiac activity. Ultimately, this body of work continues to pave the way for future biofeedback training interventions. When considering the results presented in this thesis, this somewhat elusive training method could provide an objective aid for accelerating skill acquisition, helping athletes develop more robust processes under pressure, and/or facilitate coaching practices. More specifically, if underpinned by multidisciplinary research as presented in this thesis, biofeedback methods could provide coaches and practitioners with greater objectivity in the evaluation of development and performance, e.g., the creation of meaningful and beneficial pre-performance routines. The rapid advancement in wearable technology will help facilitate the development of a training aid such as this and promote its value within an applied context.

Limitations and Future Directions

Use of cohesive multidisciplinary methods, such as performance and psychophysiological measures, are a substantial strength of this thesis. However, potential limitations of the research methodology must be considered when interpreting the combined findings. Firstly, conclusions of this thesis relating to the intake-rejection hypothesis must be mindful of physiological influences such as, muscle and metabolic activity, respiration, and postural changes. As discussed across chapters, the main opposing theorist to Lacey and Lacey's (1970, 1974, 1980) interpretation of phasic bradycardia is Obrist (1968), who proposed the alternative cardiac-somatic coupling and uncoupling model. In contradiction of the visceral afferent feedback pathway proposed by the intake-rejection hypothesis, Obrist (1968) suggests that HR deceleration is a result of a reduction in muscular and metabolic demands. Whilst tonic and pre-movement muscle tension data from chapter two suggests this model to be unfounded, a lack of evidence in later chapters in this regard is a potential oversight. Respiratory sinus arrythmia could similarly be viewed as influential in terms of the HR deceleration phenomenon. Despite previous work (Neumann and Thomas, 2009) determining that respiration is probably not correlated with HR deceleration in golf putting, not measuring breathing in this thesis may be viewed as a limitation. Furthermore, knowledge of pre-performance routine behaviours (e.g., postural changes, additional movements, and psychological processes) and timings of these relevant to distinct features of the HR deceleration pattern (e.g., initiation of deceleration), could have enriched findings. By establishing these behaviours relative to movement initiation, this thesis may have been better positioned to further oppose the cardiac-somatic coupling and uncoupling theory.

Secondly, whilst specific limitations of individual chapters rather than common themes of this thesis, skill level and performance measures could have been notable methodological flaws in chapters four and five respectively. Compared to previous studies (Cooke *et al.*, 2014; Neumann & Thomas, 2009), the smaller magnitude of HR deceleration seen in chapter four could have meant variability may have been less powerful for analysis purposes, as within-participant changes on a repeated measures basis may have been too small to identify. Equally, the performance measure in chapter five was not as strong as it could have been in terms of considering results related to performance outcome. Whilst consistency is a key characteristic of expertise, and thus performance (Fitts & Posner, 1967), performance-based conclusions in the final empirical chapter were not as clear as a target related outcome measure would have provided.

Finally, as described across chapters, the lack of multi-level modelling or similar individualistic analysis (Bertollo *et al.,* 2012) could have impeded the detection of inter- and intra-individual nuances. For example, the high variability found in chapter four for the single pressure manipulation compared to other experimental conditions, suggests that participants may have exhibited different patterns of HR deceleration. Previous work has found that predisposed anxiety can affect HR deceleration (Hassmén & Koivula, 2001), whilst probabilistic individual zones of optimal functioning (Bertollo *et al.*, 2012) suggests that optimal HR deceleration may require individualisation. Overall, analysis methods which are able to account for and embrace individual differences as part of the interpretative process may not only be important for performance application within athletes, but they could provide greater insight within psychophysiological research.

In summary of this general discussion, future work should consider the following when building on the findings presented in this thesis. Further exploration of isolated pressure scenarios in terms of the mechanistic properties and associated psychophysiological effects will help clarify application of pressure manipulations in performance under pressure research. Moreover, consideration should be given as to how individual responses may influence findings, and whether single trial pressure manipulations could prove more insightful both in an applied and laboratory setting. Applied methodology in particular, may extend this research to help make results more meaningful by allowing researchers to overcome limitations linked to manufactured pressure. Whilst these suggestions are not necessarily novel within the literature, the attention pie chart self-report tool and rate of HR deceleration model offered in this thesis, do provide a new perspective. Future studies should focus on further validating the attention pie chart by replicating previous attentional focus studies and concurrently applying established metrics, such as the Movement Specific Reinvestment Scale (Orrell *et al*., 2009). The rate of HR deceleration model offered in this thesis, should similarly be tested using traditional skill acquisition paradigms. For example, learning and skill transfer protocols may confirm that attention efficiency can only be developed through the acquisition of expertise. Likewise, the manipulation of task difficulty in an expert novice comparative study might further show that attention efficiency is a feature of expertise. Although this thesis provides preliminary evidence that rate of HR deceleration is a correlate of performance, further work exploring HR deceleration relative to successful and unsuccessful performances, may help to determine attention efficiency as an important element of skilled motor performance. However, to unequivocally establish continued support in favour of the intake-rejection hypothesis, future studies should ensure the employment of methods which enable the elimination of muscular, metabolic, and respiratory influences on preparatory cardiac activity.

General Conclusion

Despite Baumeister’s (1984) paper on choking under pressure having been cited over 2000 times, little empirical evidence exists to substantiate the assumption that all pressures are equal. Accordingly, this thesis aimed to psychophysiologically challenge this position. The combined results of this thesis demonstrate that depending on the pressure applied, different psychophysiological responses may be exhibited. Thus, researchers should be more mindful of methodological design when exploring performance under pressure.

Secondly, whilst measures exist to analyse conscious processing (Cooke *et al*., 2011; Orrell *et al*., 2009), this thesis found results to be relatively one-dimensional. In essence, whilst internal focus of attention can be assessed in terms of increases/decreases, these measures do not allow researchers to determine how other aspects of attentional focus may have been disrupted. As such, a novel self-report measure which assesses attentional focus from a more multi-dimensional perspective is presented.

Finally, although the intake-rejection hypothesis (Lacey & Lacey, 1970, 1974, 1980) was first proposed over 50 years ago, few studies have aimed to test it since. Those that have, have generally focused on the magnitude of HR deceleration varying as a function of expertise (e.g., Neumann & Thomas, 2009). However, the attentional implications of this theory are synonymous with tasks which have the potential to disrupt attentional processes. For instance, the introduction of a secondary task may limit the ability of an individual to reinvest, increased task difficulty may require greater attentional processes, and performance under pressure could disrupt optimal attention. As such, this thesis used manipulations based on these themes to further explore the intake-rejection hypothesis. Whilst HR deceleration was established in two previously explored contexts and one novel task, in contrast to previous narrative which in line with attention literature implied the magnitude of bradycardia may be important for performance, the rate of HR deceleration proved to be the best correlate of performance. A new model associated with the rate of HR deceleration being indicative of attentional efficiency is presented as a result.

In combination, the findings presented in this thesis highlight the previously unexplored potential value of the intake-rejection hypothesis and adds further support in favour of the mechanistic properties. Successful sports performance is highly sought-after, and with attentional processes an apparently key element of optimal skilled motor performance under pressure, hopefully this thesis helps to enlighten the academic and applied community in terms of the development of an objective measure which could inform future biofeedback training interventions.

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APPENDICES

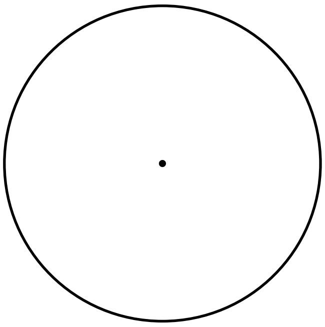
1. Attention Pie Chart

1A) Used in chapter four i.e., dart specific

Slice the pie to indicate what you were focusing on during the previous block of throws (i.e., before movement onset):

Internal task-related (A)
(e.g., posture, joint position,
Grip tension)

(C) Internal task-unrelated
(e.g., breathing, hunger,
body temperature)



External task-related (B)
(e.g., dart, target)

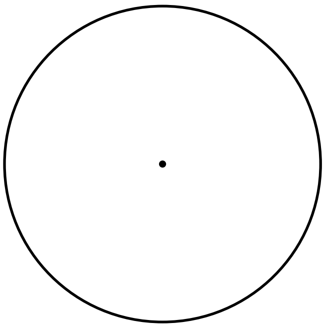
(D) External task-unrelated
(e.g., surroundings, noise,
experimenter or other people)

1B) Used in chapter five i.e., golf specific

Slice the pie to indicate what you were focusing on during the previous block of shots (i.e., before movement onset):

Internal task-related (A)
(e.g., posture, joint position,
grip tension)

(C) Internal task-unrelated
(e.g., breathing, hunger,
body temperature)



External task-related (B)
(e.g., ball, target,
club, surface)

(D) External task-unrelated
(e.g., surroundings, noise,
experimenter or other people)