EFFECTS OF COMPETITION ON PERFORMANCE, AND THE UNDERLYING PSYCHOPHYSIOLOGICAL MECHANISMS

BY

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ABSTRACT

This thesis investigates potential psychophysiological mechanisms to explain the effects of competition on performance. In the first experiment novice participants undertook a golf putting task under varying levels of competitive pressure. Fewer putts were holed with increased competitive pressure. Mediation analyses revealed that effort, muscle activity and lateral clubhead acceleration were responsible for the decline in performance. In the second experiment, expert golfers completed a putting task under varying levels of competitive pressure. Results indicated that increased competitive pressure improved performance, in terms of how close putts finished to the hole. Mediation analyses revealed that effort and heart rate partially mediated improved performance. In the third experiment, participants undertook a handgrip endurance task in competitive and non-competitive conditions. Results indicated that endurance performance was greater during competition. Enjoyment fully mediated whereas effort and heart rate variability partially mediated the effects of competition on performance. In the final experiment, participants undertook a handgrip endurance task in individual and team competitions. Endurance performance was better during team competitions. Mediation analyses revealed that enjoyment and effort mediated the effects of competition on performance. These findings are discussed in relation to processing efficiency, reinvestment, and enjoyment-based theories of the competition–performance relationship.

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LIST OF PAPERS

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PROLOGUE

"Of all human powers operating on the affairs of mankind, none is greater than that of competition."

Senator Henry Clay, US Secretary of State, 1825–1829.

It is well established that competition can influence our performance across a range of domains, including sport. For example, Usain Bolt, the 2008 Beijing Olympic champion and world record holder over 100 and 200 meters, views competition as a tool that can help improve his performance. When asked about the prospects of breaking his world records at the beginning of the 2010 season, he said: "For me, I think it is possible because there are going to be a lot of head-to-heads next season… last season there weren't really a lot of head-to-heads… but when there are three great athletes in one race, anything is possible." (Telegraph, 22nd November 2009).

On the other side of the coin, there are those for whom the pressures associated with the biggest competitions of all seem to be too much to handle. Paula Radcliffe, the marathon world record holder and favourite for gold going into the 2004 Athens Olympics, famously failed to finish the race. She felt in good condition leading up to the race and had trained so that she was prepared for the Greek weather conditions, leading to her tearful admission that she simply did not know what went wrong (BBC, 23rd August 2004). Despite holding world records for the 10 km road race and the marathon, and being a gold medallist at European, Commonwealth, and World Championships, she has failed to medal in all four of her Olympic Games.

In spite of these well documented effects that important competitions can have on performance, the underlying mechanisms of the competition–performance relationship remain a source of debate (cf. Beilock & Gray, 2007). Accordingly, with the goal of increasing our understanding of the social psychology of competition, this thesis investigates the psychological and physiological processes that drive competition-induced changes in performance, with a particular focus on performance during competitive sport. It is hoped that in uncovering the mechanisms that are responsible for mediating performance during competition, researchers, athletes and practitioners will be able to develop targeted intervention strategies to promote superior performance and prevent incidences of choking under competitive pressure.

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CHAPTER ONE

"Competition is a social process that is so pervasive in Western civilization that none can escape it. Indeed the pervasiveness of competition has so polarized our views that some people shun it and others glorify it. Apathy toward competition is not a problem; extreme emotion and irrational thought frequently are." Martens (1975) p. 66.

General Introduction

As Martens alludes to (in the quote above), competition is highly prevalent across society. He defines competition as a process "in which the comparison of an individual's performance is made with some standard in the presence of at least one other person who is aware of the criterion for comparison and can evaluate the comparison process" (Martens, 1975, p.71). Indeed, how we perform a given task when compared to others can define excellence. Furthermore "win-lose" terms are a common feature in the language of domains ranging from business and politics to education and sport. For example, a businessman "achieves" a promotion, the prime minister "wins" the general election, a pupil is "top of the class" and a boxer "defeats" his opponent.

In addition to the social comparison and evaluation associated with competition, it often includes rewards for success. Church's (1968) view of competition is that it is a situation where rewards are distributed to individuals in an unequal fashion, depending on how they perform a given activity when compared to others. This reward-based definition seems particularly applicable to competitive sport. For instance, in the Olympic Games, the fastest athlete is awarded the most prestigious gold medal, while the third fastest runner receives the impressive, but less important bronze.

Because of the social comparison, evaluation, and rewards within sporting competition, it elicits pressure to perform well (Baumeister & Showers, 1986), and is considered an acute psychological stress (Jones & Hardy, 1990). Martens's observation that competition elicits stress responses such as "extreme emotion and irrational thought" supports this view of competition. Accordingly, based on this assessment of competition, theories of emotion/stress/pressure and performance could account for incidences of competition-induced changes in performance in sport. An overview of the effects that competition can have on motor performance is provided next. In the subsequent sections, three theories that might provide an explanation of the effects of competition on sports performance are outlined.

Effects of Competition on Motor Performance

The relationship between competition and motor performance has received research attention for over one hundred years. It was 1898 when Norman Triplett published his classic studies examining the effects of competition on the speed at which cyclists rode their bikes. He observed that cyclists rode faster when racing against other cyclists than they did in timed trials that were completed alone. His subsequent laboratory experiment, which is presented in the same manuscript, noted that most participants were able to turn a fishing reel faster when in competition than when operating alone. This is generally credited as being the seminal social psychology experiment (Harackiewicz & Tauer, 2006).

Since Triplett's work, several studies have added further detail to our knowledge of how competition influences our behaviour. In 1975, Martens reviewed the two dozen or so studies that had examined the effects of competition on motor performance. His analysis suggested that competition tended to improve the performance of muscular endurance and strength tasks, plus those skills that were simple or well-learned. In contrast, competition could impair the performance of complex tasks and those that were not well learned. This observation clearly resonates with early theories of social facilitation (i.e., Zajonc, 1965), which sought to explain how the presence of others influenced performance. Zajonc (1965) suggested that the presence of others increases an individual's level of drive (i.e., physiological arousal), which, in turn, promoted the individual's dominant response tendency. For simple and well-learned tasks, the dominant response tendency was the correct response, and hence, an audience could improve the performance of such tasks. In contrast, an audience could impair the performance of complex or new tasks, as the dominant response tendency here is often suboptimal skill execution.

It intuitively makes sense for the effects of competition on performance to closely resonate with the effects of observers on performance, given the considerable social comparison and evaluation elements that are present in competition. However, this account of the evaluation–performance relationship has been criticised for being too simplistic (cf. Landers & McCullagh, 1976) and, moreover, a recent meta-analysis yielded only weak support for its predictions when applied to sport performance (Strauss, 2002). Anecdotal evidence also challenges this view of the competition–performance relationship, as there are several examples of elite athletes crumbling under competitive pressure (e.g., Greg Norman blowing a six shot lead in the final round of the 1996 Masters golf championships – he was ranked world number one at the time). If an audience during competition promotes the dominant response, which for elite athletes is presumably a high level of performance, then such incidences of choking under pressure should not happen. As a consequence, recent research attention has shifted away from drive theories, such as Zajonc's (1965) model of social facilitation, towards attentional/emotional theories, that might offer a better explanation of the effects of competition on performance (Beilock & Gray, 2007). Some of these theories are introduced later in this chapter.

The most recent review of the literature into the effects of competition on motor performance was conducted by Stanne, Stanne and Johnson in 1999, and considered the results of sixty-four studies, demonstrating the continued research interest in this field. Rather than focusing on the type of task as a moderator of the effects of competition on performance, they compared the effects of competition to the effects of cooperation and individualistic efforts. Their conclusions were that, overall, cooperative goal-structured activities led to better performance than activities performed in competition. However, competition led to better performance than was achieved in individual "do your best" goal-structured conditions. This analysis again clearly demonstrates that different social climates of performance, including competition, frequently influence our motor performance.

A criticism of the utility of this review and its applicability to sport is its constant comparison of competition with cooperation. By nature, sport is competitive and examples of sporting tasks that are purely cooperative in nature do not easily come to mind. Indeed, even in team sports, where cooperation with team mates is evident, competition, in the form of a rival team, is ever present. In fact, such team, or intergroup competitions, were included in Stanne et al.'s (1999) meta-analysis within the cooperation category. As was noted by Tauer and Harackiewicz (2004), it would seem just as logical to categorise these team activities as competition. If this had been so, the gulf in performance during cooperation versus competition may have been different (cf. Tauer & Harackiewicz, 2004).

A second limitation of the utility of this meta-analysis is that it gives little insight into the mediators of the different effects of competition and cooperation on motor performance.

This could be viewed as a step back from the earlier work done by Martens (1975), which at least attempted to fit the effects of competition on performance to a theoretical framework (i.e., social facilitation). An understanding of the mechanisms that underlie the competition–performance relationship is important for two reasons. First, it is intuitive that uncovering the factors that cause competition to influence performance will in future yield more accurate predictions concerning its effects on performance. Second, an understanding of the mechanisms will allow targeted interventions designed to promote the pattern of psychophysiological responses to competition that will most likely yield a facilitative effect on performance.

In sum, competition clearly has the capability to influence performance (Martens, 1975, Stanne et al., 1999). This effect was first reported by Triplett in 1898, and has been investigated by numerous other researchers in the years since. General patterns have emerged regarding the moderating role of the type of task being performed. In simple or well learned tasks, as well as those based largely on muscular endurance, speed, or strength, competition is likely to have a facilitative effect on performance. Such tasks are highly prevalent in sports. However, competition does not always facilitate performance of these tasks (Strauss, 2002). As a consequence, the models of social facilitation that have been used to describe the general patterning of the effects of competition on performance do not have reliable predictability, and fail to provide a satisfactory explanation of the competition–performance relationship in sport (cf. Landers & McCullagh, 1976). A more contemporary approach to the investigation of the effects of competition on performance explores potential underlying mechanisms of the competition–performance relationship (Beilock & Gray, 2007). This is the approach that was adopted in the experiments that are described later in this thesis.

As previously alluded to, competition can be considered an acute psychological stress which elicits pressure to perform well. As a consequence, theories designed to explain the effects of emotion/stress/pressure on performance may apply to the competition–performance relationship. The key theories that were examined as potential explanations of the effects of competition on performance in the experimental chapters of this thesis are outlined in the following sections.

Processing Efficiency Theory

Processing efficiency theory (Eysenck & Calvo, 1992) offers one potential explanation of changes in performance under pressure in competitive sport (Wilson, 2008; Woodman & Hardy, 2001). Processing efficiency theory is an attentional theory that attributes changes in performance to the effects of anxiety, a negative emotion that is often experienced during competition (Mullen, Hardy & Tattersall, 2005), on working memory. It is an evolution of earlier theories of anxiety-induced cognitive interference (e.g., Sarason, 1984; Wine, 1971). These theories argue that anxiety elicits worrisome thoughts, which can interfere with task relevant information processing, and consequently impair performance. Eysenck and Calvo (1992) acknowledged some studies which supported the predictions of cognitive interference theories (e.g., Deffenbacher, 1978; Sarason & Stoops, 1978). However, they also highlighted several studies that found no difference in performance between individuals experiencing high and low levels of worry (e.g., Blankstein, Toner & Flett, 1989; Calvo, Alamo & Ramos, 1990). Wine’s (1971) and Sarason’s (1984) simplistic theories that associated anxiety with impaired performance could not account for these findings. Accordingly, within processing efficiency theory, Eysenck and Calvo (1992) argued that worry is not solely associated with attentional interference, but that it also has a second, motivational function, which increases effort and can allow performance to be maintained or even improved.

Processing efficiency theory is seated within Baddeley's tripartite model of the working memory system (Baddeley 1986). This system consists of three components arranged in a hierarchical fashion. At the peak is the central executive, which is a limited capacity control centre that is responsible for active processing and self regulatory function, such as performance monitoring and strategy selection (Eysenck, Derakshan, Ramos & Calvo, 2007). There are also two slave systems, namely, the phonological loop, which is responsible for rehearsal and storage of verbal information, and the visuospatial sketchpad, which is responsible for the storage of visual and spatial information (Derakshan & Eysenck, 2009). According to processing efficiency theory, the main effects of anxiety are on the central executive component of the working memory system.

As outlined previously, Eysenck and Calvo (1992) suggested that anxiety has two effects on the central executive. First, it consumes attentional capacity through worry. When attentional capacity is consumed to the extent that no auxiliary resources remain to retain on-task attention, performance is impaired. This is consistent with the earlier models of cognitive interference. The second function of anxiety, according to processing efficiency theory, is to increase effort. This motivational reaction to anxiety is triggered by a self-regulatory system within the working memory (see Eysenck & Calvo, 1992; Hockey, 1986), when it detects that anxiety is beginning to harm performance. The increased effort that follows can maintain or even enhance performance by mobilizing auxiliary processing resources that increase the amount of attention devoted to a task. A key distinction is therefore made between performance effectiveness (i.e., the quality of performance) and processing efficiency (i.e., effectiveness divided by expended effort). As performance can be maintained by compensatory increases in effort, Eysenck and Calvo (1992) argue that anxiety impairs efficiency more than effectiveness.

The majority of the evidence upon which processing efficiency theory is based comes from studies of cognitive task performance. Accordingly, although the theory was intended to have general applicability, the authors acknowledged that it should have most relevance to cognitive performance. However, several studies of motor performance have yielded some support for the predictions of processing efficiency theory. For example, in a field study Smith, Bellamy, Collins and Newell (2001) explored the relationships between anxiety, effort, and performance of volleyball players under different conditions of competitive pressure during a volleyball season. All players, regardless of dispositional anxiety, increased the amount of effort that they exerted when pressure increased, indexed by set criticality (i.e., point spread separating the teams). However, when exerting extra effort, the performance of low-trait anxious players improved, whereas the performance of high-trait anxious players deteriorated. This suggests that the extra effort invested by those low in anxiety mobilised additional attentional resources that led to performance improvement. In contrast, highly-anxious players performed worse because their attentional capacity was exceeded by more worrisome thoughts.

Similarly, Hardy and Hutchinson (2007) also used a “real-world” sport setting to examine the predictions of processing efficiency theory. Specifically, they conducted three experiments in which performance, anxiety, and effort were recorded as rock climbers scaled a challenging rock face. The exact climbing tasks varied based on the difficulty rating of the climb and whether or not the climber led or top-roped the route (leading a route is more risky than top-roping because less safety clips are in place to secure the rope attached to the climber’s harness should he or she fall). It was hypothesised that more difficult climbs, and those that were led compared to top-roped, would elicit greater anxiety and effort. These hypotheses were broadly supported. Effort was greater during the more difficult climbs and those that were led as opposed to top-roped in all three studies. Cognitive anxiety was greater during these climbs in two of the three studies. Performance, indexed by ratings awarded by an experienced observer, improved with additional effort in two of the three studies, but was impaired in the most anxious climbers in the remaining study. These findings support the suggestion that anxiety has both attentional and motivational effects, and that anxiety impacts processing efficiency more than performance effectiveness.

In addition to field studies, a handful of laboratory-based psychophysiological studies have also examined processing efficiency theory. The use of objective psychophysiological measures to assess psychological processes is beneficial as they are continuous, covert, and online, and thus are not subject to some of the threats to validity that are apparent in self-report measures (Blascovich, 2006). Wilson, Smith and Holmes (2007) conducted one study that adopted this multi-measure approach. They assessed the putting accuracy of golfers under high and low-pressure conditions while measuring anxiety, effort, and heart rate variability. Heart rate variability is often assessed in low (0.02- 0.06 Hz), mid (0.07- 0.14 Hz) and high (0.15- 0.50 Hz) frequency bands of the heart rate spectrum (Mulder, 1992). Changes in heart rate variability are caused by variations in parasympathetic and/or sympathetic neural influences and primarily reflect the influence of temperature (low-frequency band), blood pressure (mid-frequency band), and respiration (high-frequency band) on cardiac control (Jorna, 1992). Reduced heart rate variability in the mid-frequency band has also been demonstrated during effortful processing (see Mulder, 1992). Accordingly, mid-frequency heart rate variability is proposed as a physiological measure of effort (Jorna, 1992; Mulder, 1992). Wilson et al. (2007) found that self-reported effort and anxiety increased in the high-pressure condition but heart rate variability in the mid-frequency band and putting accuracy remained unchanged. The absence of a reduction in heart rate variability may have been due to ventilatory changes under pressure that were not assessed. Consistent with processing efficiency theory, increased self-reported effort allowed performance effectiveness to be maintained despite increased anxiety in the high-pressure condition. However, as greater effort was required to achieve the same level of performance in the high-pressure condition as was achieved in the low-pressure condition, processing efficiency was reduced.

It should be noted that attentional control theory (Eysenck et al., 2007) has recently been offered as an extension to processing efficiency theory. This update introduces more specificity regarding the attentional systems and central executive functions involved in performance, but importantly, the new theory still accounts for anxiety-induced changes in performance through the mechanisms outlined by its predecessor. The notion that anxiety compromises efficiency to a greater extent than effectiveness is the core feature of both theories.

Reinvestment Theory

An alternative psychological explanation of changes in motor performance under competitive pressure is offered by reinvestment theory (Masters & Maxwell, 2008). Before outlining the central tenets of this theory, it is useful to describe Fitts and Posner’s (1967) model of skill acquisition, upon which the principles of reinvestment theory are based. Fitts and Posner (1967) noted that novices tend to adopt a hypothesis testing strategy when trying to learn a new skill. This typically involves learners making several conscious adjustments to technique in order to ascertain an optimal way to perform a task. Such a strategy builds conscious knowledge of the components of the skill. As novices improve and become more expert-like, skills are performed with less conscious attention, because the conscious knowledge that originally supported the skill is consolidated into more automized motor programs (Salmoni, 1989). Accordingly, Fitts and Posner (1967) proposed a skill acquisition continuum where the cognitive demands of a skill start off as conscious, and eventually become autonomous.

Subscribing to this view of attention during learning, Deikman (1969) pointed out that reinvesting actions with attention can undo automization. Reinvestment theory suggests that the anxiety experienced in high-pressure competitions directs attention inward (cf., Baumeister, 1984) and could trigger such a reinvestment of conscious knowledge, causing the deautomization of a skill (Masters & Maxwell, 2008). As a result, this theory provides a potential explanation of incidences where highly skilled experts (e.g., Paula Radcliffe, Greg Norman) choked during competition in sport. Specifically, impaired performance under pressure would occur because reinvestment, and the more conscious mode of processing that this promotes, represents a regression to an earlier and less effective stage of movement control (Masters & Maxwell, 2008).

Several studies have yielded results that are compatible with reinvestment theory. For example, Masters, Polman and Hammond (1993) found that golfers who scored higher on the reinvestment scale (developed by Masters et al., 1993 to assess the likelihood of an individual reinvesting explicit knowledge under pressure) were more likely to perform worse at a putting task when under pressure than those who scored lower on the scale. Furthermore, they found that tennis and squash players’ scores on the reinvestment scale correlated with the likelihood of them choking under pressure – players who scored higher on the scale were rated by their coach as being more likely to fail under the pressures of competition.

While the results of this study provide some support for reinvestment theory (i.e., dispositional reinvestment seems to moderate the effects of competition on performance), they provide no direct evidence that reinvesting explicit knowledge to consciously control performance induces failure (i.e., mediates the effects of competition on performance). However, some evidence that suggests a mediating role of conscious processing in the competition–performance relationship has been provided. For example, Beilock, Carr, MacMahon and Starkes (2002) showed that skilled golfers putted less accurately when attention was consciously focused on their swing than when they were being distracted by a concurrent tone counting task. This effect was replicated by Gray (2004) with a sample of college baseball players – they made more temporal swing errors on a simulated batting task when consciously focusing on their swing.

As is the case with processing efficiency theory, some studies have also incorporated psychophysiological and kinematic measures to provide results that are compatible with reinvestment theory. For example, Weinberg and Hunt (1976) measured anxiety and electromyographic activity while participants threw a tennis ball at a target. After completing half of the trials (low-pressure condition), participants received failure feedback (high-pressure condition). Results showed that participants who experienced high levels of anxiety contracted their agonist (biceps) and antagonist (triceps) muscles for longer than the low-anxious participants during the high-pressure condition. This indicated reduced neuromuscular efficiency with elevated anxiety and pressure. The authors speculated that these individuals may have used an internal focus of attention to cortically steer their movements. In other words, adopting a conscious control of movements under pressure caused a regression to a less efficient level of movement control.

In a similar vein, a recent study by Lohse, Sherwood and Healy (2010) examined the effect of an internal versus an external focus of attention on electromyographic activity and dart throwing performance. They found that participants were less accurate (indicated by darts landing further from the bullseye) and less efficient (indicated by increased electromyographic activity in the triceps) when they were asked to focus internally (i.e., consciously focus on their arm motion) than when focusing externally (i.e., on the dart). Thus, an internal focus of attention seemed to induce conscious motor processing which reduced muscular efficiency and impaired performance, as would be predicted by reinvestment theory.

Competition-induced changes to the kinematics of movement could also indicate reinvestment. For example, a series of climbing studies found that participants took longer to traverse a wall at heights in excess of four metres (high-pressure condition), compared to an identical traverse at heights of less than half a metre (low-pressure condition) (Pijpers, Oudejans, & Bakker, 2005; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008). This was attributed to a more novice-like motor control strategy. Specifically, participants made more and longer-lasting reaching movements in the high-pressure condition.

Movement kinematics have also been analysed in studies of golf putting. A one-dimensional analysis of the kinematics of the back and forth movement of the club indicated that less accurate putting under conditions where demands on working memory resources were high (as occurs when one is anxious) was associated with increased jerkiness and decreased smoothness during the downswing (Maxwell, Masters, & Eves, 2003). This also could represent a regression from the smooth and efficient movement control of experts to the jerky and inefficient control of novices (cf. Delay, Nougier, Orliaguet & Coello, 1997).

An Enjoyment Model

As an alternative to the previously described attentional theories, an enjoyment-based model (e.g., Tauer & Harackiewicz, 2004) focuses on the effects of competition on a positive emotion, namely, joy. In brief, an enjoyment model contends that competitions can increase enjoyment, which can lead to improvements in performance (Tauer & Harackiewicz, 2004).

This model was informed by anecdotal evidence to suggest that competitions can elicit positive feelings. For instance, we know that individuals routinely seek out competitive experiences (e.g., play competitive sport), and it is difficult to envisage people engaging in such activities if they have only aversive psychological consequences. Moreover, Joe Paterno, the successful and longest serving coach in American Football famously stated: “We strive to be number one, but win or lose, it is the competition that gives us pleasure” (Tutko & Bruns, 1976). Importantly, this anecdotal evidence is also supported by research which empirically demonstrates that competitions can elicit positive emotions such as excitement and joy (e.g., Epstein & Harackiewicz, 1992; Tauer & Harackiewicz, 2004).

The suggestion that positive emotions experienced during competitions may elicit effects on performance was voiced by Totterdell (2000). Specifically, he provided evidence that professional cricketers experience varying degrees of happiness over the course of a four-day county championship match. Importantly, the amount of happiness experienced was correlated with ratings of performance – cricketers performed better in sessions of play when they were happier (Totterdell, 2000).

To build on this previous research, Tauer and Harackiewicz (2004) experimentally examined the effects of positive emotion on performance during competition. Specifically, they conducted a series of studies which demonstrated that team competitions reliably increased enjoyment and basketball shooting performance. Next, they applied mediation analyses to statistically examine enjoyment as an underlying mechanism of the observed facilitative effect of competition on performance. They found increased enjoyment was partially responsible for improved performance during competition. This finding introduced the enjoyment model of performance, and clearly highlighted its potential as a mechanism to explain any facilitative effects of competition on performance in sport.

Tauer and Harackiewicz's enjoyment model is compatible with Fredrickson's broaden-and-build theory of positive emotion (Fredrickson, 2004), which outlines the effects of positive emotions such as joy on our thoughts and actions. Fredrickson notes that negative emotions, such as anxiety and anger, are associated with very specific action tendencies (e.g., anxiety with escaping danger, anger with the urge to attack) (Lazarus, 2000). She contrasts these negative emotions with positive emotions, which according to the theory, serve to broaden thought-action repertoires and build personal resources. For example, joy creates the urge to play and be creative, and interest creates the urge to explore and expand the self by taking in new experiences. Importantly, Fredrickson (2004) suggests that the personal resources (e.g., becoming more creative and knowledgeable) that are accrued from experiencing positive emotion outlast the transient period when the positive emotion was felt. In this way, positive emotions serve to foster positive traits that seed "human flourishing" (Fredrickson, 2004). Accordingly, Fredrickson argues that positive emotions not only signal optimal functioning, but that they also produce it.

Unlike processing efficiency theory and reinvestment theory, enjoyment and positive emotion models (e.g., Fredrickson 2004; Tauer & Harackiewicz, 2004) are not classic theories of stress and performance that are frequently cited in sport psychology literature. However, when applied to the competition–performance relationship, the enjoyment model has already demonstrated its potential as a mechanism to explain competition-induced improvements in performance in sport.

In addition to self-report measures, psychophysiological measures could also be acquired to examine positive emotions during competitive sport. For example, the autonomic nervous system can reflect positive emotions (e.g., Levenson, 1992). Within their biopsychosocial model of challenge and threat, Blascovich and colleagues (e.g. Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004) have validated increased heart rate coupled with increased cardiac contractility as an autonomic measure of increased engagement, which is characteristic of a positive emotional state (Fredrickson, 2004). A shortening of the cardiac pre-ejection period is one measure of increased cardiac contractility (Sherwood et al., 1990). The pre-ejection period is the time between the onset of the electrical contraction of the heart and the onset of left-ventricular ejection (Harrison Denning, Easton, Hall, Burns et al., 2001). Increased heart rate and a shortening of the cardiac pre-ejection period occurred during a remote-control car racing competition, when compared to resting and non-competitive conditions, in studies by Harrison et al. (2001) and Veldhuijzen van Zanten, De Boer, Harrison, Ring, Carroll et al. (2002). These findings provide some psychophysiological evidence that competition elicits a positive emotional state. Unfortunately, performance was not assessed in these two studies, meaning the effects of increased engagement on performance could not be evaluated.

Summary

In sum, previous research has established that competition influences performance in sport (e.g., Martens, 1975; Stanne et al., 1999). However, the mechanisms that mediate the effects of competition on performance remain a source of debate. Processing efficiency theory and reinvestment theory have emerged as popular models of the competition–

performance relationship in sport psychology literature (see Masters & Maxwell, 2008; Wilson 2008). Processing efficiency theory offers an effort-based account of incidences of improved performance under competitive pressure. When performance is impaired during competition, processing efficiency theory attributes this to anxiety overloading our limited attentional capacity. In contrast, reinvestment theory offers an alternative account of impaired performance under competitive pressure, whereby increased anxiety causes reinvestment of conscious knowledge, deautomization, and accordingly, a regression to a more novice-like stage of movement control. Unlike processing efficiency theory and reinvestment theory, positive emotion models have received little research attention from sport psychologists, but could provide an account of improved performance during competition. Specifically, an enjoyment model (Tauer & Harackiewicz, 2004) suggests that competition-induced improvements in performance should be mediated by increased enjoyment.

All of these theories have generated promising mechanisms to explain competition-induced changes in performance. The supporting evidence has been predominantly based on experiments that employed self-report assessments of the key variables (e.g., anxiety, effort, reinvestment, enjoyment). However, an increasing number of experiments have incorporated objective physiological and kinematic measures to indicate the psychological processes that are implicated in the competition–performance relationship in sport. Such a multi-measure approach is advantageous as it can provide stronger evidence for theoretical predictions. This approach is a feature of the experimental work described later in this thesis. Some of the limitations of previous research, which the experiments reported in this thesis were designed to overcome, are described next. In overcoming previous limitations, it was hoped that the findings of the experiments would yield a more comprehensive account of the competition–performance relationship than has previously been provided.

Limitations of Previous Research

Two general limitations of previous research curtail the ability of any of the aforementioned theories to claim that they provide a comprehensive account of the mechanisms that underlie changes in performance during competitive pressure. First, although research has documented that competition affects performance and produces changes in psychological (e.g., anxiety, effort), physiological (e.g., muscle activity) and kinematic (e.g. acceleration) variables, only one study (i.e., Tauer & Harackiewicz, 2004) has examined whether such changes *cause* the change in performance. This issue of causality could be tested using mediation analyses. These analyses provide examination of putative underlying mechanisms that support changes in a given dependant variable and are increasingly advocated in experimental psychology to provide stronger tests of theoretical predictions (cf. MacKinnon, 2008).

Second, although several studies have assessed psychological, physiological, and movement-related effects of competition in isolation, few studies (e.g., Pijpers et al., 2005; Wilson et al., 2007) have assessed them simultaneously. As previously mentioned, the use of physiological measures to assess psychological processes is beneficial as physiological measures are continuous, covert, and online, and thus are not subject to some of the threats to validity that are apparent in self-report measures (Blascovich, 2006). Moreover, they provide corroborative and hence stronger evidence that changes in physiological responses reflect underlying psychological processes. Accordingly, a multi-disciplinary approach has been recommended to provide fuller insights into the mechanisms that underlie changes in performance under competitive pressure in sport (Beilock & Gray, 2007; Nieuwenhuys, et al., 2008).

Aside from these general limitations, there are also specific limitations that relate to individual elements of the various theories and experiments that have examined them. These limitations are covered in the introductions of each of the four experimental chapters that follow.

Aims of Thesis and Outline of Experimental Chapters

With the goal of increasing our understanding of the social psychology of competition, this thesis investigates the psychological and physiological processes that drive competition-induced changes in performance. The primary purpose was to examine the variables implicated in the aforementioned theoretical accounts as mediators and moderators of the effects of competition on performance in sport. It is hoped that in uncovering the underlying mechanisms of the competition–performance relationship, researchers, athletes and practitioners will be able to develop targeted intervention strategies to promote superior performance and prevent incidences of choking under competitive pressure. The experimental work that follows is novel because it represents the first set of experiments to comprehensively characterise the effects of multiple levels of competitive pressure at psychological, physiological and kinematic levels of analysis. Moreover, it applies statistical mediation analyses to formally examine the putative causal roles of variables identified by processing efficiency theory, reinvestment theory, and an enjoyment model.

The experiment reported in chapter two concurrently examined psychological, physiological and kinematic responses to, as well as performance under multiple levels (low, medium, high) of competitive pressure. It was designed to examine the predictions of processing efficiency theory. The primary purpose was to examine whether increased competitive pressure is associated with changes in performance and to formally evaluate possible causes using mediation analyses. Based on processing efficiency theory, effort was expected to mediate performance, should it improve with pressure, and anxiety to mediate performance, should it deteriorate with pressure. Moreover, neuromuscular and kinematic changes were hypothesised as additional mediators of performance if it was impaired with increased levels of competition. A golf putting task was employed and novice golfers were recruited as participants.

To build on this experiment, the experiment presented in chapter three concurrently examined expert golfers' psychological, physiological, kinematic, and performance responses to competitive pressure. By using expert golfers as participants, the study was designed to examine the predictions of processing efficiency theory and reinvestment theory. Again, the primary purpose was to establish causes of competition-induced changes in performance through mediation analyses. Processing efficiency theory predicted that effort should mediate performance, if it improved with pressure, and anxiety should mediate performance, if it deteriorated with pressure. Alternatively, reinvestment theory predicted that conscious processing should mediate performance, if it deteriorated with pressure. Finally, neuromuscular, grip force and kinematic changes were hypothesised as additional mediators of performance if it was impaired with increased levels of competition.

To examine the effects of competition on a different task, the experiment reported in chapter four examined the effects of competition on endurance performance. It included self-report and objective physiological measures of emotional state to test the predictions of processing efficiency theory and an enjoyment model of the competition performance relationship. Mediation analyses were implemented to highlight which theoretical account provided the best explanation of the competition–endurance performance relationship. A handgrip endurance task was employed. Processing efficiency theory predicted that effort should mediate endurance time if it increased with competition, and anxiety should mediate endurance time, if it decreased with competition. In contrast, an enjoyment model suggested that enjoyment should mediate endurance performance if it was improved with competition.

Finally, to build on chapter four, the experiment presented in chapter five examined the effects of different types of competition (i.e., individual and team) on performance. This experiment was designed to further evaluate processing efficiency theory and an enjoyment model as accounts of the competition–performance relationship. Based on the work of Tauer and Harackiewicz (2004), it was hypothesized that team competitions would elicit better performance than individual competitions. This was based on the suggestion that the cooperation inherent in team competitions should increase positive emotions (e.g., joy), which, according to the enjoyment model, should mediate any improved performance during competition. Alternatively, processing efficiency theory predicted that effort should be responsible for improved performance. The same handgrip endurance task as was used in the previous experiment was employed, with endurance time serving as the measure of performance.

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CHAPTER TWO

Psychological, Muscular and Kinematic Factors Mediate Performance under Pressure

Abstract

It is well established that performance is influenced by competitive pressure, but the mechanisms that underlie this relationship are poorly understood. To address this important issue, the current experiment evaluated psychological, physiological and kinematic factors as mediators of the pressure–performance relationship. Psychological, physiological and kinematic responses to three levels of competitive pressure were measured in 23 males and 35 females during a golf putting task. Pressure manipulations impaired putting performance and increased anxiety, effort, heart rate, heart rate variability, muscle activity and lateral clubhead acceleration. Mediation analyses revealed that effort, muscle activity and lateral acceleration partially mediated the decline in performance. Results confirmed that competitive pressure elicits effects on performance through multiple pathways.

Introduction

Pressure to perform well is elicited by situational incentives such as social comparison, evaluation, and rewards for success (Baumeister & Showers, 1986). As these factors are common features of sporting competition (Martens, 1975), the relationship between pressure and performance has been frequently examined in the sport domain (e.g. Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Jackson, Ashford, & Norsworthy, 2006). However, the precise mechanisms that underlie changes in motor performance under competitive pressure remain a source of debate (Beilock & Gray, 2007).

Processing Efficiency Theory

Processing efficiency theory (Eysenck & Calvo, 1992) offers a psychological explanation of changes in performance under competitive pressure in sport (Wilson, 2008; Woodman & Hardy, 2001). The theory attributes these changes to the effects of anxiety, that accompanies pressure (Mullen, Hardy & Tattersall, 2005), on our limited attentional capacity. It is based on Baddeley's (1986) tripartite model of working memory, which consists of a limited capacity control center (central executive), a subsystem for verbal information processing (phonological loop), and a subsystem for visual and spatial information processing (visuospatial sketchpad). The main effects of anxiety are purportedly on the central executive, which is responsible for active processing and self-regulatory functions (e.g., performance monitoring and strategy selection) (Eysenck, Derakshan, Ramos & Calvo, 2007).

According to processing efficiency theory, anxiety has two effects on the central executive component of the attentional system. First, it consumes attentional capacity through worry. When attentional capacity is consumed to the extent that no auxiliary resources remain to retain on-task attention, performance is impaired. Second, it increases effort. Increased effort can enhance performance by mobilizing auxiliary processing resources that increase the amount of attention devoted to a task. A key distinction is made between performance effectiveness (i.e., the quality of performance) and efficiency (i.e., effectiveness divided by effort expended). As performance effectiveness can be maintained by compensatory increases in effort, anxiety is proposed to impair efficiency more than effectiveness.

Williams, Vickers, and Rodrigues (2002) examined processing efficiency theory in sport. Table tennis players were required to execute shots towards targets under high and low states of anxiety, where high anxiety was created by evaluation and competition. Results indicated that performance effectiveness, indexed by shot accuracy, was impaired with increased anxiety. Moreover, increased self-reported effort, probe reaction time, and number of eye fixations during ball tracking were noted with high anxiety, providing evidence that anxiety reduced processing efficiency. A similar finding was made by Wilson, Smith, Chattington, Ford and Marple-Horvat (2006). They demonstrated that increased anxiety had a detrimental effect on driving performance, and processing efficiency, indexed by self-report and eye-gaze measures. These studies are compatible with the explanation of impaired performance that is offered by processing efficiency theory.

Support for processing efficiency theory's account of maintained performance under pressure was recently offered by Wilson, Smith and Holmes (2007). They assessed the putting accuracy of golfers under high and low-pressure conditions while measuring anxiety, effort, and heart rate variability. Heart rate variability is often assessed in low (0.02- 0.06 Hz), mid (0.07- 0.14 Hz) and high (0.15- 0.50 Hz) frequency bands of the heart rate spectrum (Mulder, 1992). Changes in heart rate variability are caused by variations in parasympathetic and/or sympathetic neural influences and primarily reflect the influence of temperature (low-frequency band), blood pressure (mid-frequency band), and respiration (high-frequency band) on cardiac control (Jorna, 1992). Reduced heart rate variability in the mid-frequency band can also indicate increased mental effort (Mulder, 1992). Wilson et al. (2007) found that self-reported effort and anxiety increased in the high-pressure condition but heart rate variability in the mid-frequency band and putting accuracy remained unchanged. The absence of a reduction in heart rate variability may have been due to respiratory changes under pressure that were not assessed. Consistent with processing efficiency theory, increased self-reported effort allowed performance effectiveness to be maintained despite increased anxiety in the high-pressure condition. However, as greater effort was required to achieve the same level of performance in the high-pressure condition as was achieved in the low-pressure condition, processing efficiency was reduced. The aforementioned studies show that changes in performance under pressure are consistent with the predictions of processing efficiency theory (Wilson, 2008).

Neuromuscular and Kinematic Effects of Pressure

Beyond the boundaries of processing efficiency theory, other variables emerge as candidates that could further explain the effects of competitive pressure on motor performance. For example, muscle tension can increase with increased pressure (e.g., Duffy, 1932), potentially disrupting motor performance. To test this suggestion, Weinberg and Hunt (1976) measured anxiety and electromyographic activity while participants threw a tennis ball at a target. After completing half of the trials (low-pressure condition), participants received failure feedback (high-pressure condition). Results showed that participants who experienced high levels of anxiety contracted their agonist (biceps) and antagonist (triceps) muscles for longer than the low-anxious participants during the high-pressure condition. This indicated reduced neuromuscular efficiency with elevated anxiety and pressure. Participants low in anxiety improved their performance, assessed by throwing accuracy, in the high-pressure condition. Performance did not change in those high in anxiety. Reduced neuromuscular efficiency appeared to be the factor that prevented the high-anxiety participants recording a performance improvement. This finding indicates that increased muscle tension under pressure could have an important influence on performance.

Recent climbing studies have also adopted a multi-disciplinary approach to understanding the effects of pressure on performance by assessing the kinematics of movement (Pijpers, Oudejans, & Bakker, 2005; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008). They found that novice climbers took longer to traverse a wall at heights in excess of four metres (high-pressure condition), and made more and longer-lasting reaching movements, compared to an identical traverse at heights of less than half a metre (low-pressure condition). Movement kinematics have also been analysed in studies of golf putting. A one-dimensional analysis of the kinematics of the back and forth movement of the club allowed less accurate putting under conditions where demands on working memory resources were high (as occurs when one is anxious) to be attributed to increased jerkiness and decreased smoothness during the downswing (Maxwell, Masters, & Eves, 2003). However, no effects of competitive pressure on the kinematics of the putting stroke were noted by Mullen and Hardy (2000) following a two-dimensional kinematic analysis that considered both club and arm movement. Taken together, these studies provide some evidence that competitive pressure is associated with less efficient movement kinematics. Disruption to movement kinematics could provide another mechanism through which pressure exerts detrimental effects on performance.

The Present Study

The literature reviewed above suggests that competitive pressure can exert effects on performance through a variety of pathways. However, previous research should be interpreted in light of some methodological limitations. First, although research has documented that competitive pressure affects performance and produces changes in psychological (e.g., anxiety, effort), physiological (e.g., muscle activity) and kinematic (e.g. acceleration) variables, it has not established that changes in these variables *cause* the change in performance. This could be tested using mediation analyses (cf., Wilson, Chattington & Marple-Horvat, 2008). Second, although several studies have assessed psychological, physiological, and movement-related effects of pressure in isolation, few studies (e.g., Williams et al., 2002; Wilson et al., 2006) have assessed them simultaneously. A multi-disciplinary approach has been recommended to provide fuller insights into the mechanisms that underlie impaired performance under competitive pressure in sport (Beilock & Gray, 2007; Nieuwenhuys, et al., 2008). Third, previous golf putting studies have examined kinematics of the putting stroke in one-dimension (Maxwell et al., 2003) and two-dimensions (Mullen & Hardy, 2000), but none have characterized the effects of pressure in three-dimensions (i.e., back-and-forth, lateral and vertical axes of clubhead movement).

In light of these limitations, the present study aimed to concurrently examine psychological, physiological and three-dimensional kinematic responses to, as well as performance under multiple levels (low, medium, high) of competitive pressure. The study is the first to investigate the effects of multiple levels of pressure on behavior in sport, with previous research comparing only two levels of pressure (i.e., low versus high). It was hypothesized that the experimental manipulations of pressure would elicit increases in anxiety, and effort (Eysenck & Calvo, 1992). Pressure was also expected to decrease heart rate variability in the mid-frequency band (Mulder, 1992) and increase heart rate (Woodman & Davis, 2008), cardiovascular indices of increased effort and anxiety, respectively. In addition, it was predicted that pressure would increase muscle activity (Weinberg & Hunt, 1976) and disrupt kinematics (Maxwell et al., 2003), which are indices of inefficient movements. The primary purpose was to examine whether increased competitive pressure is associated with changes in performance and to formally evaluate possible causes using mediation analyses. Based on processing efficiency theory, effort was expected to mediate performance, should it improve with pressure, and anxiety was expected to mediate performance, should it deteriorate with pressure. Moreover, it was hypothesized that neuromuscular and kinematic changes would prove additional mediators of performance if it was impaired with increased pressure.

Method

Participants

Male (*n* = 23) and female (*n* = 35) right-handed undergraduate students participated in the experiment in exchange for course credit. Participants (*M* age = 19.6 years, *SD* = 1.2 years) were enrolled in a sport science degree program. All were novice golfers with no formal playing experience or official handicap. Informed consent was obtained from all participants.

Equipment

A standard length (90 cm) steel-shafted blade style golf putter (Sedona 2, Ping) was used to putt regular-size golf balls (diameter = 4.27 cm) towards a half-size hole (diameter = 5.5 cm; depth = 2.8 cm). A half-sized hole was adopted to increase the accuracy demands of the task. The hole was located 1.5 m from the end and 0.7 m from the side of a 7 m long × 1.4 m wide strip of a green putting mat (Patiograss). The putting surface had a Stimpmeter reading of 4.27 m, making it faster than the greens at most American golf courses, which, according to the US Golf Association (n.d.), generally range from 2.13 m to 3.66 m.

Design

This experiment employed one within-subjects factor, pressure condition, with three levels: low, medium, and high. Participants completed five blocks of six putts. Blocks one and two helped acclimatization with the task demands, whereas blocks three, four and five represented comparatively low, medium, and high-pressure conditions, respectively.

Performance Measures

Both the number of putts successfully holed in each condition and mean radial error (i.e., the mean distance of the balls from the hole) were recorded as measures of performance (Mullen & Hardy, 2000). Zero was recorded and used in the calculation of mean radial error on trials where the putt was holed (Hancock, Butler, & Fischman, 1995).

Psychological Measures

State anxiety. Anxiety was measured using the 5-item cognitive and 7-item somatic anxiety subscales of the Competitive State Anxiety Inventory-2 Revised (Cox, Martens, & Russell, 2003). Participants were asked to indicate how they felt ‘right now’ in relation to each item, for example “I am concerned about performing poorly” and “I feel jittery”. Each item was scored on a 4-point Likert scale (1 = *not at all*, 2 = *somewhat*, 3 = *moderately so*, 4 = *very much so*). The item responses were averaged and multiplied by ten to provide one score for each subscale. Reliability coefficients of .83 for cognitive anxiety, and .88 for somatic anxiety were reported by Cox et al. (2003), showing a good level of internal consistency. In this experiment, alpha coefficients across the three pressure conditions were good for both cognitive (all .80) and somatic (.75 to .92) anxiety.

Effort. Effort was measured using the Rating Scale for Mental Effort (Zijlstra, 1993). Participants were instructed to rate the level of mental effort that they expended using a vertical axis scale ranging from 0–150, with nine category anchors, including, at the extremes, 3 (*no mental effort at all)* and 114 *(extreme mental effort)*. The scale has acceptable test-retest reliability, with a correlation coefficient of .78 (Zijlstra, 1993), and has been used previously to assess mental effort in sport (e.g., Wilson et al., 2007). In this experiment, the correlation coefficients among the three pressure conditions ranged from .73 to .85.

Physiological Measures

Cardiac activity. To assess heart rate and heart rate variability, an electrocardiogram was measured using three silver/silver chloride spot electrodes (Cleartrace, ConMed) in a modified chest configuration. The electrocardiographic signal was amplified (ICP511, Grass), filtered (1–100 Hz), and digitized at 2500 Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design) using Spike2 software (Cambridge Electronic Design). Heart rate and two time domain indices of heart rate variability (SDNN, r-MSSD) for each condition were derived from the intervals between R-waves of the electrocardiogram. The SDNN (standard deviation of R-R intervals) is a correlate of the 0.04 – 0.15 Hz frequency domain based spectral power band, $r = .84$, $p < .0001$ (Carrasco, Gaitan, Gonzalez & Yanez, 2001), which includes the 0.07 – 0.14 Hz component that Mulder (1992) considers to be sensitive to variations in effort. r-MSSD (root mean square of successive R-R intervals) is a correlate of the frequency domain-based high spectral power band (0.15–0.40 Hz) (r-MSSD, $r = .97$, $p < .0001$) (Carrasco et al., 2001). The time domain correlates of the frequency bands were assessed due to the brevity of each recording epoch (block of putts, low pressure *M* = 163 s, *SD* = 17 s, medium pressure *M* = 161 s, *SD* = 19 s, high pressure *M* = 234 s, *SD* = 20 s), which, coupled with slow heart rates of some participants, left insufficient R-R intervals to perform spectral analyses.

Muscle activity. Electromyographic activity of the extensor carpi radialis and biceps brachii muscles of the left arm was recorded; these muscles were chosen based on previous studies implicating them in the putting stroke (Smith, Malo, Laskowski, Sabick, Cooney et al., 2000; Stinear, Coxon, Fleming, Lim, Prapavessis & Byblow, 2006). Muscle activity was measured using single differential surface electrodes (DE 2.1, Delsys) and an amplifier (Bagnoli-2, Delsys) with a ground electrode on the collar bone. Electromyographic signals were amplified, filtered (20-450 Hz) and digitized (2500 Hz).

The electromyographic signal for each trial was rectified and the mean amplitudes (microvolts) were calculated by averaging the activity over four consecutive periods: pre-initiation baseline, upswing, downswing, post-contact follow-through. The duration of these periods was calculated from the Z-axis acceleration profile (described below). The upswing lasted from movement initiation until the top of the swing; the duration of the pre-initiation baseline was the same as the duration of the upswing. The downswing lasted from the top of the swing until ball contact; the duration of the post-contact follow-through was the same as the duration of the downswing. The trial values in each condition were averaged to provide a condition mean value for each electromyographic variable.

Kinematic Measures

Movement kinematics. Acceleration of the clubhead in three axes was recorded using a tri-axial accelerometer (LIS3L06AL, ST Microelectronics). Acceleration on the X, Y and Z axes corresponded to lateral, vertical and back-and-forth movement of the clubhead, and assessed clubhead orientation, clubhead height, and impact velocity, respectively. The signals were conditioned by a bespoke buffer amplifier with a frequency response of DC to 15 Hz. Both accelerometer and amplifier were mounted in a 39 mm × 20 mm × 15 mm plastic housing secured to the rear of the putter head. A microphone (NT1, Rode) connected to a mixing desk (Club 2000, Studiomaster) was used to detect the putter-to-ball contact on each trial. These signals were digitized at 2500 Hz. A computer program determined movement kinematics for each putt from the onset of the downswing phase of the putting stroke until the point of ball contact. The average acceleration was calculated for the X, Y and Z axes. Impact velocity, root mean square jerk and smoothness were also calculated for the Z axis as the primary axis involved in putting (see Maxwell et al., 2003). The values from the six trials in each condition were averaged to provide a condition mean value for each kinematic variable.

Manipulations

Based on Baumeister and Showers (1986) research concerning the additive psychological factors that produce pressure (e.g., competition, rewards, social evaluation), comparatively low, medium, and high-pressure conditions were created.

Low-pressure. Participants were informed that, blocks one, two and three comprised a study to compare putting with a black-and-white ball versus a standard white ball. In block one, participants putted a standard white ball on odd-numbered trials and a black-and-white ball on even-numbered trials. In block two, they only putted a black-and-white ball. In block three, they only putted a white ball. To encourage participants to take the same approach to putting as golfers, they were asked to “try and get the ball ideally in the hole, but if unsuccessful, to make it finish as close to the hole as possible” prior to putting in each block. It was further explained that performance was to be recorded as the average distance that putts finished from the hole, with any holed putts counting as 0 cm. However, to minimize any pressure that may have been elicited by evaluation from the experimenter, participants were told that although the distance that each putt finished from the hole would be recorded, individual performance would not be analyzed in this condition. Instead, they were informed that the data from all participants would be pooled to generate one accuracy score for the black-and-white ball and one accuracy score for the white ball. In reality, the painted and standard balls were not compared; this dummy study was designed to minimise any pressure elicited by evaluation. Data from block three constituted the low-pressure condition.

Medium-pressure. The fourth block of putts constituted the medium-pressure condition. Prior to beginning this condition, participants were reminded that the next *two* blocks comprised the competition phase of the study. They were informed that, from now on, their accuracy would be directly compared with the performance of the other participants. To emphasize the evaluative nature of this condition, participants were told that the rank-ordered mean radial error performances of the whole sample would be displayed on a noticeboard and e-mailed to all participants. They were reminded again that, ideally, they should try and get the ball in the hole, because holed putts count as 0 cm in calculating the mean radial error performance score. If unsuccessful, they were told to try to make the ball finish as close to the hole as possible. Given that evaluative conditions with financial incentives have been used previously to induce pressure (e.g., Wilson et al., 2007), participants were informed that cash prizes of £25, £20, £15, £10 and £5 would be awarded to the top five performers at the end of the study. Further, they were made aware that they would be competing against "about fifty" other participants to allow them to evaluate their chances of winning (i.e., 10% would win a prize).

High-pressure. The fifth block of putts comprised the high-pressure condition. To further increase pressure rewards and punishments were introduced. Participants were informed that they now had a chance to win an additional £12, to be awarded at the end of the session. Specifically, they were told that a £6 reward could be earned if their average distance from the hole was less than the average distance achieved by a yoked rival competitor from a previous study. In reality, this standard was their own average distance achieved in the low-pressure condition. Pilot testing indicated that this standard was perceived as both achievable and credible. Participants were verbally told this distance and visually shown it using a tape measure. It was again emphasized that they should try and get the ball ideally in the hole to give them the best chance of beating the target distance. If unsuccessful, they were to try to make the ball finish as close to the hole as possible. Following the target distance information, a stack of six £1 coins was placed in prominent view. Participants were then told that an additional £6 could also be earned in bonuses: £1 per holed putt, which was added to the stack of coins. Penalties could be incurred: £1 was removed from the stack for every putt that was worse than their yoked rival's worst putt (in reality this distance was the participant's own mean plus half of their standard deviation from the low-pressure condition). Participants were also verbally told and visually shown this distance. Finally, it was emphasized that participants would lose the entire stack of coins, including any bonuses, if they failed to better their yoked rival's mean distance.

Expectations of success and self-awareness were also introduced to further increase pressure. To increase expectations of success, participants were told that one out of two participants had won money in this condition; this information was valid with 47% winning some money (*M* = £7.15, minimum = £4, maximum = £9). To increase self-awareness, a video camera (Sony), fitted with a wide-angled lens and light, was turned on (Buss, 1980).

Full body images of the participant were prominently displayed on a color television monitor (Panasonic) located over the mat about 50 cm above the hole.

Manipulation Check

To check the effectiveness of the experimental manipulations in creating multiple levels of pressure, participants completed the 5-item pressure/tension subscale from the Intrinsic Motivation Inventory (Ryan, 1982). Participants were asked to rate items, including “I felt pressured” and “I felt very tense” on a 7-point Likert scale (*1= not at all true, 4= somewhat true, 7= very true*). The item responses were averaged to provide one score for the scale. McAuley, Duncan, and Tammen (1989) reported an internal consistency of .68 for this subscale. In this experiment, Cronbach’s alpha coefficients across the three pressure conditions were good to very good (.74 to .89). Moreover, participants completed single-item ratings to assess how competitive, engaging, and important they considered each condition using a 7-point Likert scale (0 = *not at all,* 6 = *very much so*) (Veldhuijzen van Zanten, De Boer, Harrison, Ring, Carroll et al., 2002). This was to verify that the conditions were competitive and to ensure that participants were engaged by and valued the importance of the putting tasks, as would be expected in pressured sporting competition (cf., Hardy, Beattie, & Woodman, 2007).

Procedure

The protocol was approved by the local research ethics committee. First, participants were instrumented to allow the recording of physiological measures. Then, they completed a putting task comprising five blocks of six putts. Putts were made from three distances to reduce familiarity with one particular distance (e.g., Wilson et al., 2007). The same counterbalanced order of putting distances was fixed for each block: 1.8, 1.2, 2.4, 2.4, 1.2 and 1.8 m. The first two blocks served to acclimatize participants with the task. The last three blocks represented the experimental conditions: low-pressure (block three), medium-pressure (block four), and high-pressure (block five). The order of these conditions was fixed to minimize threats to validity (e.g., reduced motivation during low-pressure) when high-pressure precedes low-pressure (Beilock & Carr, 2001).

Prior to putting in each of the three pressure conditions, the manipulation took place and then state anxiety was measured. Putting followed, and immediately after the final putt of each condition, retrospective measures of pressure and effort were obtained. Physiological measures were recorded continuously during each block.

Successful putts were recorded immediately on a data sheet. The position of any unsuccessful putt was marked by placing a sticker on the mat. The ball then was retrieved by the experimenter and placed at the next position. At the end of blocks 1-4, the distance of each marker from the hole was recorded and the marker removed from the mat. In block 5, the distance of the ball from the hole was measured after each putt to enable a £1 coin to be added to or removed from the stack.

At the end of the session participants were questioned regarding any ball preference (i.e., white versus black-and-white). Their answers indicated that the low-pressure manipulation was credible; none guessed that the dummy part of the study was false. They were then debriefed, and where appropriate, paid prize money. At the end of the study, the leaderboard was displayed and the top five performers were paid their additional prize money.

Statistical Analysis

Analysis of the performance data revealed that two participants putted at least one ball off the mat during the three pressure conditions and thus these outliers were excluded. In addition, physiological data from two participants were unscorable. Thus, the effective sample size for the analyses reported comprised 22 male and 32 female participants.

Repeated measures MANOVA was used to examine the effects of pressure condition (low, medium, high), the within-subject factor, on the performance, psychological, cardiac and kinematic variables. This revealed a significant multivariate effect for pressure condition, $F(36, 18) = 13.09$, $p < .001$, $\eta_p^2 = .96$. A separate repeated measures MANOVA was employed to examine the effects of pressure condition and swing phase, both within-subject factors, on muscle activity. This 3 Pressure Condition × 4 Swing Phase (pre-initiation, upswing, downswing, post-contact) MANOVA yielded significant multivariate effects for condition, $F(4, 50) = 3.55$, $p < .05$, $\eta_p^2 = .22$, and phase, $F(6, 48) = 5.12$, $p < .001$, $\eta_p^2 = .39$, but no condition × phase interaction, $F(12, 42) = 1.76$, $p = .09$, $\eta_p^2 = .34$. These significant multivariate effects were followed by separate ANOVAs for each variable, which are presented in the results. Significant ANOVA effects were followed by LSD post-hoc comparisons.

Finally, ANCOVA was used to assess mediation. Mediation can be tested using a variety of methods including regression, structural equation modelling, and ANCOVA (MacKinnon, 2008). The ANCOVA approach was chosen because it is recommended for experimental designs where the sample size is low and/or a within-subjects design is employed (Hoyle & Robinson, 2004). ANOVA and ANCOVA produce identical results to and are conceptually equivalent to regression analyses (Cohen, Cohen, West, & Aiken, 2003).

The multivariate method was used for reporting the results of analyses. The multivariate method minimizes the risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVA designs (Vasey & Thayer, 1987); its use can be identified by the reduced degrees of freedom reported. Wilks' lamda, the multivariate statistic (which is not reported), equals $1 - \eta_p^2$. Partial eta-squared (η_p^2) is reported as the effect size. In ANOVA this equals the adjusted R^2 obtained in regression analyses (Tabachnick & Fidell, 2001). Values of .02, .13 and .26 for η_p^2 indicate small, medium and large effect sizes, respectively (Cohen, 1992).

Results

Manipulation Check

Separate ANOVAs confirmed main effects for pressure condition on perceived pressure and self-reported ratings of importance, engagement, and competitiveness associated with each block of putts (see Table 2.1). Post-hoc comparisons showed that perceived pressure and ratings were greatest in the high-pressure condition and smallest in the low-pressure condition, confirming that the pressure manipulations, as expected, created three distinct levels of pressure.

Effects of Pressure on Performance

The effects of the pressure manipulation on putting performance are illustrated in Figure 2.1. Two Separate ANOVAs revealed a pressure condition main effect on the average number of balls holed, $F(2, 52) = 3.35$, $p < .05$, $\eta_p^2 = .11$ (Figure 2.1A), but not the mean radial error, $F(2, 52) = 0.00$, $p = 1.00$, $\eta_p^2 = .00$ (Figure 2.1B). Significantly fewer putts were holed during medium and high than during the low-pressure condition.

Table 2.1: *Mean (SD) of the Measures in each Pressure Condition*

Measure (range of scores possible)	Pressure Condition						F (2, 52)	η_p^2
	Low		Medium		High			
	M	*SD*	*M*	*SD*	*M*	*SD*		
Manipulation Check								
Perceived pressure (1-7)	3.03	1.01	4.09[a]	1.20	4.82[a,b]	1.23	91.80***	.78
Competitive (0-6)	2.96	1.62	4.74[a]	1.09	5.33[a,b]	0.80	66.82***	.72
Important (0-6)	3.09	1.25	4.48[a]	1.18	4.96[a,b]	1.15	58.37***	.69
Engaging (0-6)	4.26	0.93	4.41	1.11	4.76[a,b]	0.89	12.32***	.32
Psychological								
Cognitive anxiety (10-40)	18.82	5.17	23.30[a]	5.58	26.52[a,b]	5.86	55.75***	.69
Somatic anxiety (10-40)	12.78	3.39	15.37[a]	5.06	18.18[a,b]	6.32	32.41***	.56
Mental effort (0-150)	66.89	18.20	81.80[a]	18.25	91.02[a,b]	21.05	87.91***	.77
Physiological								
Heart rate (bpm)	79.54	12.00	80.70[a]	12.41	82.67[a,b]	14.11	9.86***	.28
SDNN (ms)	83.92	33.81	87.15	36.14	91.09[a]	33.42	4.23*	.14
r-MSSD (ms)	53.67	32.85	58.25	41.70	58.13	36.77	1.61	.06
Kinematic								
Y-axis acceleration ($m.s^{-2}$)	0.36	0.12	0.37	0.11	0.35	0.12	0.26	.01
Z-axis acceleration ($m.s^{-2}$)	3.59	1.05	3.51	0.79	3.61	0.98	1.25	.05
RMS Jerk ($m.s^{-3}$)	3.59	0.99	3.52	0.77	3.61	0.95	0.97	.04
Smoothness	43.16	18.08	42.53	15.37	41.58	13.66	0.86	.03

Note: Letters (a and b) indicate significant difference from low and medium-pressure conditions respectively. **p* <.05, ****p* <.001

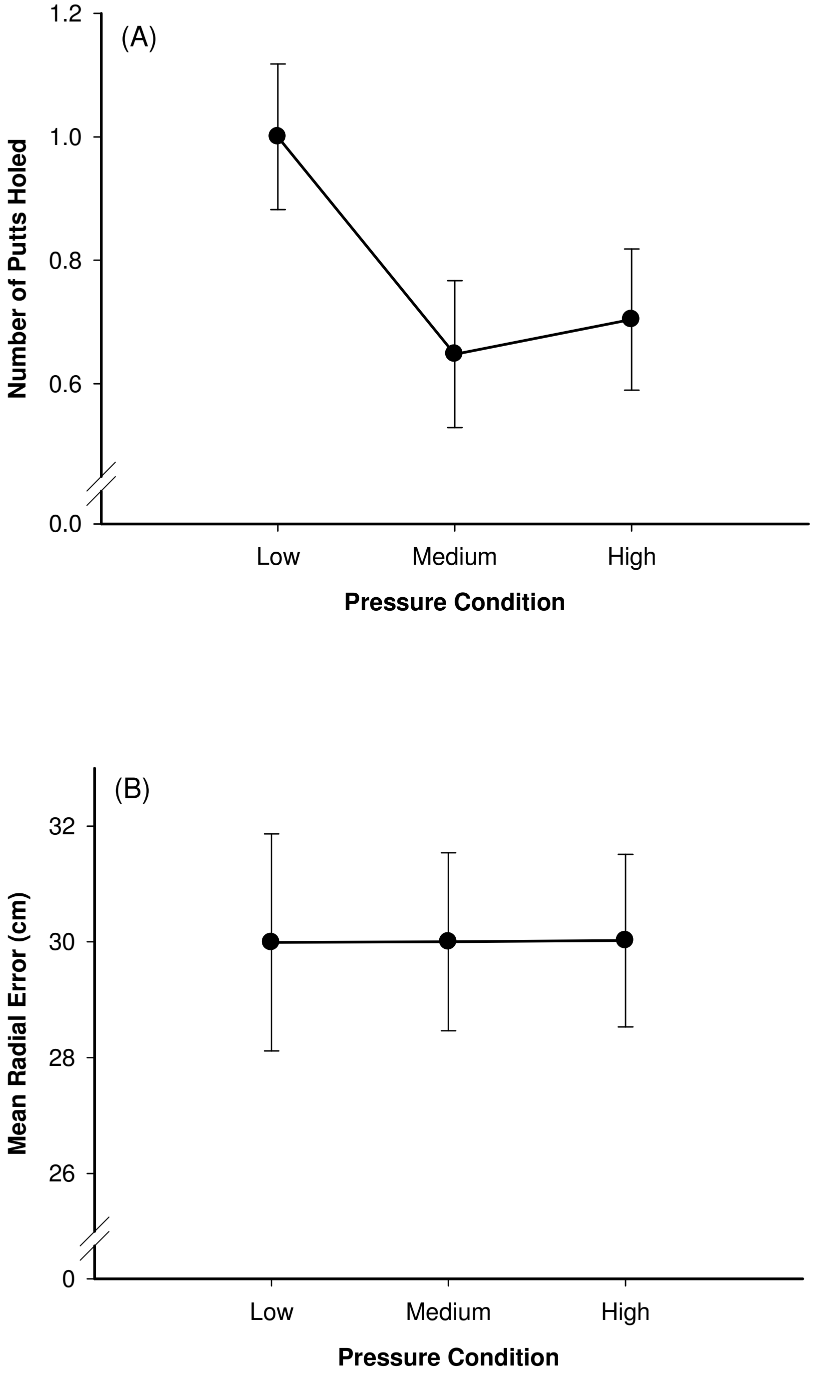


Figure 2.1. (A) Number of balls successfully holed across pressure conditions. (B) Mean radial error scores across pressure conditions. Error bars depict standard error of the means.

Effects of Pressure on Psychological Measures

ANOVAs revealed main effects of pressure condition for cognitive anxiety, somatic anxiety and effort (see Table 2.1). Post-hoc comparisons showed that anxiety and effort were greatest in the high-pressure condition and smallest in the low-pressure condition.

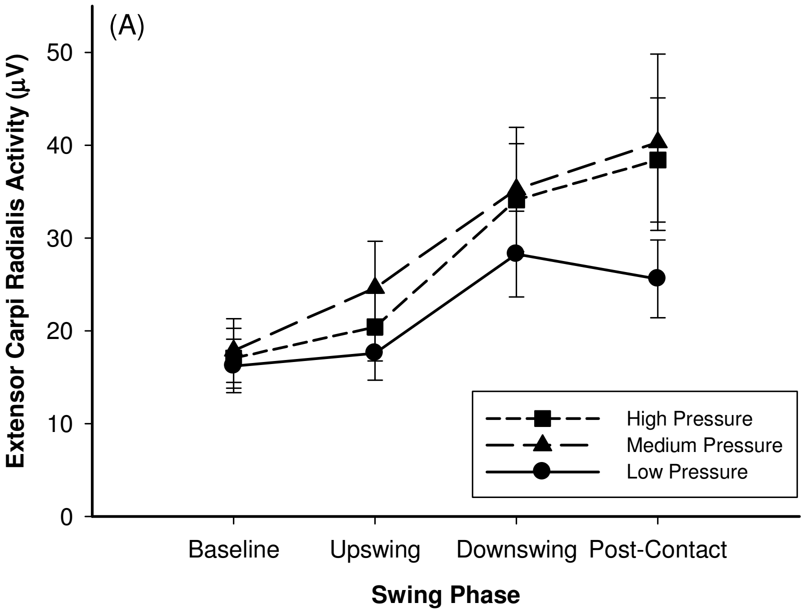
Effects of Pressure on Physiological Measures

The ANOVAs indicated a main effect of pressure condition on heart rate and SDNN but not r-MSSD (see Table 2.1). Post-hoc testing confirmed that heart rate increased from low to medium to high-pressure conditions. SDNN increased from low to high-pressure.

The effects of pressure on muscle activity are displayed in Figure 2.2. Separate 3 Condition × 4 Phase ANOVAs were conducted for each muscle. A significant condition effect for extensor carpi radialis activity was revealed, $F(2, 52) = 5.18$, $p < .01$, $\eta_p^2 = .17$; muscle activity was greater under high-pressure than low-pressure. A significant swing phase effect for the extensor carpi radialis activity was also found, $F(3, 51) = 9.96$, $p < .001$, $\eta_p^2 = .37$; muscle activity was similar at baseline through the upswing but increased significantly from upswing to downswing with no further increase thereafter. There was no condition × phase interaction, $F(6, 48) = 1.98$, $p = .09$, $\eta_p^2 = .20$. No condition, $F(2, 52) = 1.87$, $p = .17$, $\eta_p^2 = .07$, phase, $F(3, 51) = 1.43$, $p = .24$, $\eta_p^2 = .08$, or condition × phase interaction effects, $F(6, 48) = 1.09$, $p = .38$, $\eta_p^2 = .12$, were evident for the biceps brachii.

Effects of Pressure on Kinematic Measures

Figure 2.3 presents impact velocity and X-axis acceleration as a function of the pressure manipulation. The ANOVA yielded an effect for pressure condition on X-axis acceleration, $F(2, 52) = 8.74$, $p < .001$, $\eta_p^2 = .25$; lateral acceleration was greater in the high-pressure condition than the low and medium-pressure conditions.



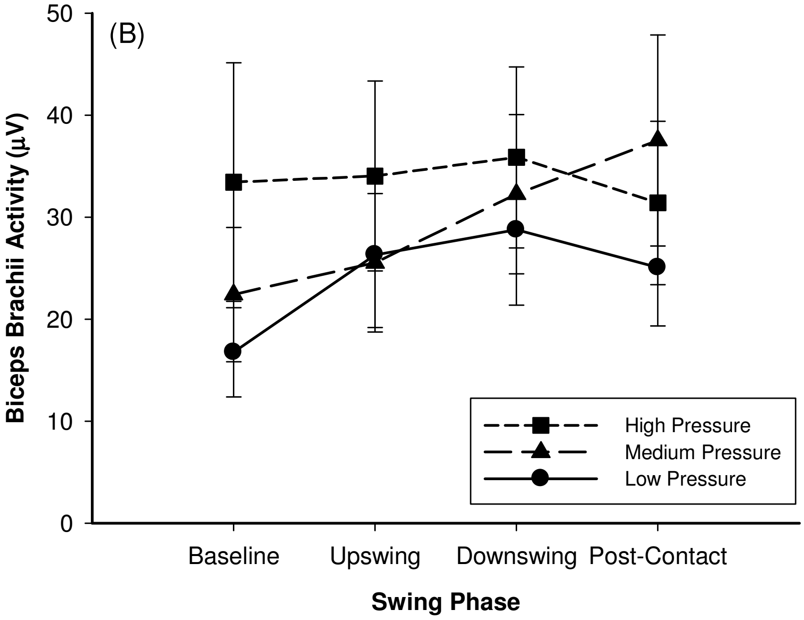


Figure 2.2. (A) Extensor carpi radialis muscle activity during each phase of the swing. (B) Bicep brachii muscle activity during each phase of the swing. Error bars depict standard error of the means.

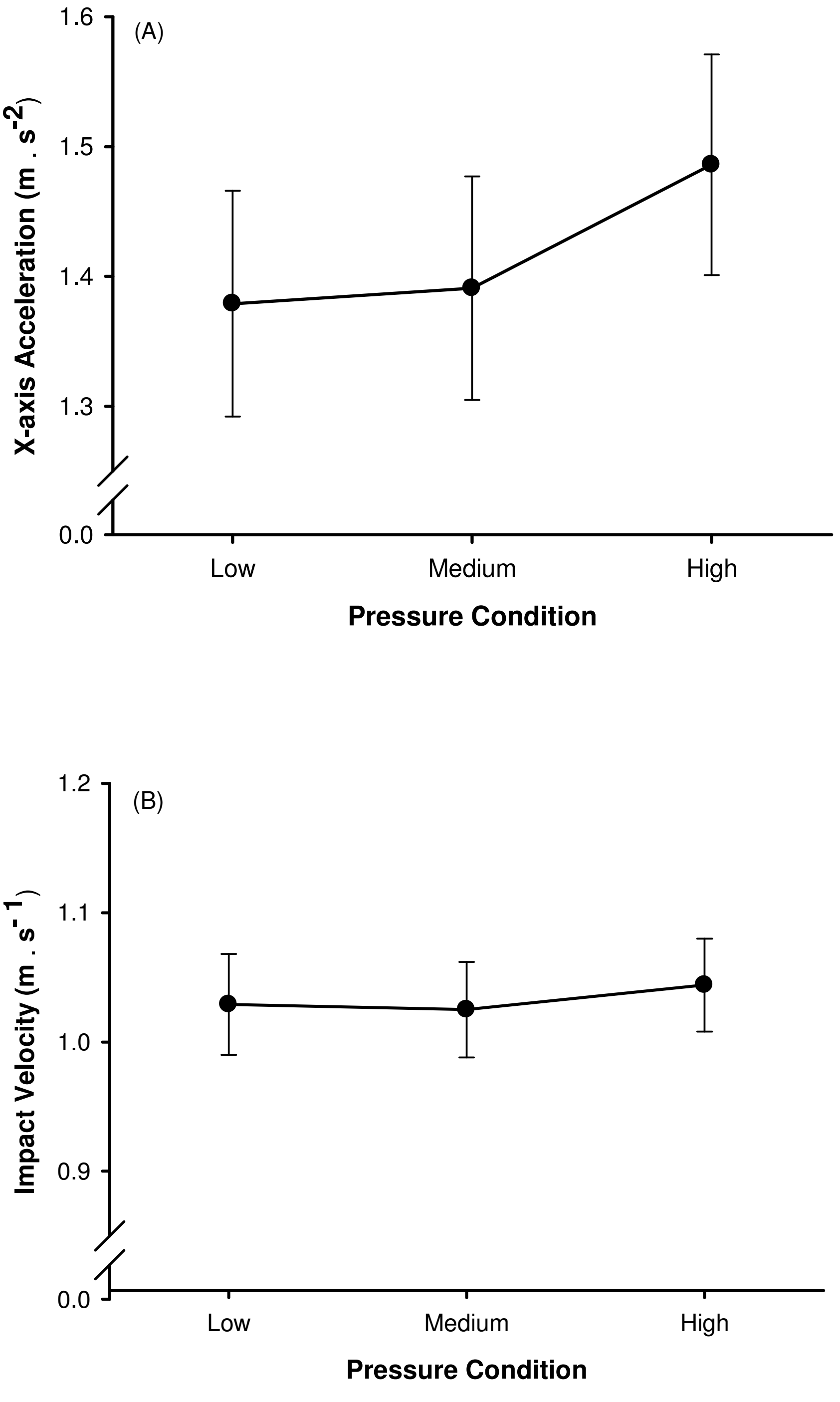


Figure 2.3. (A) X-axis acceleration across each pressure condition. (B) Impact velocity across each pressure condition. Error bars depict standard error of the means.

No main effects for pressure were revealed for impact velocity, $F(2, 52) = 1.39$, $p = .26$, $\eta_p^2 = .05$, or other kinematic measures (see Table 2.1).

Mediation Analysis

Mediation analyses were employed to test whether any of the psychological, physiological or kinematic variables mediated the significant decline in putting performance, indicated by the reduction in the number of balls holed in the medium and high-pressure conditions compared to the low-pressure condition. To establish mediation, four criteria must be satisfied (Baron & Kenny, 1986). First, the independent variable must affect the dependent variable. The main effect of pressure condition on the number of balls holed satisfied this criterion. Second, the independent variable must affect the mediator. Main effects for pressure condition on all psychological variables as well as heart rate, heart rate variability (SDNN), X-axis acceleration and extensor carpi radialis activity were found satisfying this criterion. The final two criteria are that the mediator must affect the dependent variable and that the effect of the independent variable on the dependent variable must be reduced in the presence of the mediator. Any of the psychological, physiological and kinematic variables that satisfy these final criteria can be considered mediators of the observed breakdown in performance under pressure. The change in η_p^2 associated with the pressure condition when each variable is used as a covariate indicates the importance of that variable in explaining the effects of pressure condition on putting performance (see Tabachnick & Fidell, 2001).

Repeated measures ANCOVA, with each potential mediator variable as the changing covariate, and pressure condition as a within-subjects factor were conducted to simultaneously test whether the last two criteria were met. The original analysis indicated that 11% of the variance in number of balls holed could be attributed to pressure condition;

this corresponds to a medium size effect for competitive pressure on performance. This effect did not survive the covariate adjustment for effort, $F(2, 50) = 1.32$, $p = .28$, $\eta_p^2 = .05$, extensor carpi radialis activity, $F(2, 50) = 2.15$, $p = .13$, $\eta_p^2 = .08$, and X-axis acceleration, $F(2, 50) = 1.46$, $p = .24$, $\eta_p^2 = .06$. These variables partially mediated the effect of pressure on performance; mediation was partial as a small-to-medium effect size remained. In sum, mediation analyses indicated that impaired putting performance under competitive pressure was explained in part by changes in multiple processes.

Discussion

An understanding of the causes of pressure induced changes in performance is needed to better inform individuals about how to perform optimally and protect against performance breakdown under competitive pressure. This study concurrently examined psychological, physiological and kinematic responses to multiple levels of competitive pressure. Building on previous research, the primary purpose was to formally test potential mechanisms explaining changes in performance under competitive pressure. Manipulation checks confirmed that ratings of pressure, competitiveness, importance and engagement were greatest in the high-pressure condition and smallest in the low-pressure condition. Accordingly, the pressure manipulations created increasingly important competitions that pressured and engaged participants, as per real-life sporting competition (cf., Hardy et al., 2007).

Effects of Pressure on Performance

Pressure had different effects on the two measures of performance. In terms of the outcome measure, number of putts holed, pressure had a detrimental effect on performance:

Fewer putts were holed in the medium and high-pressure conditions than in the low-pressure condition. This finding is broadly consistent with some (e.g., Wilson et al., 2006) but not all (e.g., Mullen & Hardy, 2000) studies that have used outcome measures of performance to examine the pressure–performance relationship in sport. It also resonates with anecdotal evidence. For example, Scott Hoch faced the pressure of having a simple putt to win the 1989 United States Masters Golf Championship on two occasions, but missed both times.

In terms of the accuracy measure, mean radial error, pressure had no effect on performance. This finding is also consistent with some (e.g., Wilson et al., 2007) but not all (e.g., Williams et al., 2002) studies that have adopted accuracy measures of performance. It seems that adopting a reduced hole size made the outcome measure of performance more sensitive to the effects of pressure than the accuracy measure (cf. Mullen & Hardy, 2000). Specifically, the reduced size hole minimised room for error if a successful outcome (i.e., holing a putt) was to be achieved. In contrast, the accuracy measure, mean radial error, was more likely to tolerate minor errors in aim, because although these would prevent putts from being holed, minor errors would allow the ball to finish in close proximity to the target. The mechanisms which underlie the detrimental effect of pressure on number of putts holed are discussed in the following sections.

Psychological Mediators of Performance

As was hypothesised, pressure increased anxiety. Processing efficiency theory attributes impaired performance under competitive pressure to cognitive anxiety overloading attentional capacity. Contrary to this claim, increases in cognitive anxiety caused by the pressure manipulations did not mediate the reduction in putts holed under increased pressure. It is possible that cognitive anxiety is a symptom of competitive pressure rather than a causal variable in the relationship between stress and performance (Hardy & Hutchinson, 2007).

However, it is important to point out that anxiety was assessed *pre*-performance, in accordance with the standard use of the CSAI-2R. Perhaps a measure of anxiety that reflects feelings *during* performance, such as the mental readiness form (Krane, 1994), is needed to explain changes in performance.

In line with the vast majority of previous research, increased competitive pressure was also associated with greater self-reported effort (for review see Wilson, 2008). Processing efficiency theory contends that additional effort should maintain or improve performance. Performance, in terms of mean radial error, was maintained, but not improved, with increased anxiety and pressure. Thus, mediational analyses could not evaluate the proposed beneficial role of effort on performance (Baron & Kenny, 1986). Surprisingly, when applied to the outcome measure of performance (balls holed), mediation analyses revealed that increased effort was in part responsible for the observed performance deterioration under pressure. Reinvestment and explicit monitoring theories (Beilock & Carr, 2001; Masters & Maxwell, 2008) may offer an explanation for this finding. These theories propose that additional effort under pressure can be detrimental to performance as it prompts the reinvestment of explicit knowledge to consciously guide action. This can lead to a regression from a more efficient and autonomous to a less efficient and more cognitive processing strategy.

Given that participants were novices, one might assume that they did not have explicit knowledge of the skill. However, Poolton, Masters, and Maxwell (2007) have argued that explicit knowledge is accrued when individuals make conscious attempts to identify and eradicate performance errors. Moreover, they demonstrated that novices required few trials to generate such explicit knowledge. Accordingly, by missing putts during the first three blocks of trials, the novice participants would have generated explicit knowledge that they could have reinvested in the subsequent medium and high-pressure conditions. In support of this suggestion, evidence of improvement was noted across the first three blocks of putts. Specifically, mean radial error decreased from block one (*M* = 49.74 cm) to block two (*M* = 38.82 cm) to block three (*M* = 29.99 cm), the low-pressure condition. The mean number of balls holed was similar across blocks one (*M* = 0.63) and two (*M* = 0.43), before improving in the subsequent low-pressure condition (*M* = 1.02). Thus, impaired performance observed during increased competitive pressure could reflect reinvestment of explicit knowledge.

Physiological Mediators of Performance

As expected, heart rate, a physiological index of arousal and/or anxiety, increased with pressure. Although this increase was relatively small, the finding supports most previous studies (Pijpers et al., 2005; Nieuwenhuys et al., 2008). The small size of the cardiac reaction to pressure can be explained by the effect of posture on heart rate; stress-induced cardiac reactivity is blunted when participants stand (Veldhuijzen van Zanten, Thrall, Wasche, Carroll, & Ring, 2005). Increased heart rate did not mediate the effects of pressure on performance.

Decreased heart rate variability in the mid-frequency spectral band is a putative psychophysiological measure of effort (Mulder, 1992). SDNN, a correlate of heart rate variability in the 0.04 - 0.15 Hz spectral power band that includes the mid-frequency band (i.e., 0.07 - 0.14 Hz), increased rather than decreased under conditions of increased pressure. This finding may reflect an increase in respiratory volume under pressure (Jorna, 1992). However, if this were the case then a more substantial increase in variability would be expected in the high-frequency band that is most sensitive to respiratory changes. No change in r-MSSD, a correlate of heart rate variability high-frequency, was noted. That self-reported effort increased, but heart rate variability did not decrease mirrors the finding of Wilson et al.

(2007). It is possible that the postural and physical demands of the golf putting task, although minimal, override the effects of mental activity on cardiovascular measures (cf. Veldhuijzen van Zanten et al., 2005). These findings argue against the use of heart rate variability as a reliable measure of mental effort during sport.

A next hypothesis was that muscular activity would be augmented by increased pressure. Extensor carpi radialis muscle activity was elevated by pressure, concurring with the findings of Weinberg and Hunt (1976). Activity in this muscle also increased as a function of swing phase. This can be explained by a cumulative increase in the number of active motor units due to new recruitment in each successive movement phase. As the velocity at which the ball was struck remained unchanged, it seems that the increase in overall muscle activity in the high-pressure relative to the low-pressure condition was a result of tighter gripping of the club rather than changes to the dynamics of the swing. In support of this argument, Smith et al. (2000) reported higher grip force in line with increased forearm extensor muscle activity in golfers prone to impaired putting under competitive pressure. Increased extensor carpi radialis muscle activity partially mediated the deterioration in performance under pressure, a finding consistent with anecdotal evidence, specifically, the suggestion that golfers ‘tense up’ when they miss putts during competition.

No effects were found for biceps brachii activity. The lack of an effect of competitive pressure on bicep activity may be attributed to participants over-contracting this muscle in the low pressure condition, thus clouding the effects of increased pressure in the subsequent conditions. In support of this contention, Smith et al. (2000) and Stinear et al. (2006) showed that experienced golfers activated their extensor carpi radialis more than their biceps brachii when putting. In this study of novices, overall extensor carpi radialis activity ($M = 26.81$ μV) and biceps brachii activity ($M = 30.35$ μV) did not differ ($p = .59$). Thus, it seems likely that the novice participants displayed inefficient muscle activity in the bicep even before the introduction of pressure. The lack of differential activity across swing phase suggests that this muscle was not activated by the putting stroke as executed by novice golfers.

Kinematic Mediators of Performance

The hypotheses that movement kinematics would be disrupted by the pressure manipulations and that changes in kinematics would mediate impaired performance were supported. Lateral acceleration of the clubhead increased with competitive pressure and partially mediated impaired performance. This finding provides new insights concerning the kinematic basis for missed putts when performing under competitive pressure. Specifically, additional lateral acceleration implies that the putter was swung out of line during increased pressure. Given that putter face angle and path determine 83% and 17% of ball direction, respectively (Pelz, 2000), greater lateral acceleration would have changed the putter path and should have disrupted the putter face angle. The net result would have been that competitive pressure altered the line on which the ball was struck. This account of missed putts is consistent with what golfers refer to as ‘pulling’ and ‘pushing’ putts wide of the hole when under pressure.

That misalignment of the clubhead at impact caused missed putts under pressure is further supported by the observation that impact velocity did not change across the pressure conditions. This finding rules out the possibility that more balls were understruck or overstruck.

Limitations of the Study and Directions for Future Research

The results should be interpreted in light of some methodological limitations. First, performance was assessed as the average of six putts, whereas pressure-induced failure in sport is typically a one-off event (e.g., you may only get one chance to sink a putt to win).

However, single-trial performance is characterized by large variability and poor reliability (e.g. Woodman & Davis, 2008). Performance was assessed over six putts in an attempt to strike a balance between ecological validity (1 putt; Woodman & Davis, 2008) and measurement reliability (20 putts; Wilson et al., 2007). Nevertheless, the effects of pressure may have been diluted by assessing performance over multiple trials, as participants had chances to redeem bad putts. Second, the number of putts holed did not differ between the medium and high-pressure conditions. This null finding might be attributed to either an insufficient increase in pressure between conditions or to a floor effect in the number of balls holed. Specifically, performance fell from 1 out of 6 balls holed in the low-pressure condition to 0.6 in the medium-pressure, leaving little room for further deterioration with additional pressure. Future studies could design a task in which performance has more room for deterioration. Third, attentional capacity and allocation of resources were not assessed. This was to help maximise the ecological validity of the pressure manipulations. However, in employing dual-task paradigms or attentional probing tasks, future research could more directly test the predictions of attention-based theories of performance in sport (see Beilock, Carr, MacMahon, & Starkes, 2002; Murray & Janelle, 2003). Finally, only novice golfers were recruited. It is likely that different mechanisms regulate expert performance under pressure (Gray, 2004). Reinvestment theory (Masters & Maxwell, 2008) may offer one such mechanism for impaired performance under pressure in experts who have explicit knowledge of their skill. Future research should examine expert performance in this context.

Conclusion

By simultaneously assessing psychological, physiological and kinematic measures, the present study adds to the mounting evidence that competitive pressure concurrently elicits effects at multiple levels of analysis (Pijpers et al., 2005; Nieuwenhuys et al., 2008).

In particular, a novel kinematic explanation of missed putts under competitive pressure was outlined. Mediation analyses did not support the predictions of processing efficiency theory as an explanation for failure under pressure in sport. It remains for future research to continue with this promising multi-disciplinary approach and paint a richer picture of the pressure and performance relationship.

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CHAPTER THREE

Effects of Competitive Pressure on Expert Performance: Underlying Psychological, Physiological and Kinematic Mechanisms

Abstract

Although it is well established that performance is influenced by competitive pressure, our understanding of the mechanisms which underlie the pressure–performance relationship is limited. The current experiment examined mediators of the relationship between competitive pressure and motor skill performance of experts. Psychological, physiological and kinematic responses to three levels of competitive pressure were measured in 50 expert golfers, during a golf putting task. Elevated competitive pressure increased putting accuracy, anxiety, effort and heart rate, but decreased grip force. Quadratic effects of pressure were noted for self-reported conscious processing and impact velocity. Mediation analyses revealed that effort and heart rate partially mediated improved performance. The findings indicate that competitive pressure elicits effects on expert performance through both psychological and physiological pathways.

Introduction

Because sports competitions often include social comparison, evaluation, and rewards for success (Martens, 1975), they elicit pressure to perform well (Baumeister & Showers, 1986). Accordingly, the relationship between competitive pressure and motor skill performance has been frequently examined in sport (e.g. Beilock & Carr, 2001; Gucciardi & Dimmock, 2008). However, previous studies, for the most part, have failed to test potential mediators of any effects of competitive pressure on performance. As a consequence, our understanding of the mechanisms that underlie pressure-induced changes in performance is limited. This study investigated whether psychological, physiological and kinematic processes mediate the effects of competitive pressure on motor performance.

Processing Efficiency Theory

One psychological description of the effects of pressure on motor performance is offered by processing efficiency theory (Eysenck & Calvo, 1992). It is based on Baddeley's (1986) tripartite model of working memory, which includes a limited capacity control center (central executive) that is responsible for active processing and self-regulation (Eysenck, Derakshan, Ramos & Calvo, 2007). Processing efficiency theory attributes pressure-induced changes in performance to the effects of anxiety – which is elicited by pressure (Mullen, Hardy & Tattersall, 2005) – on the capacity limited central executive. According to processing efficiency theory, anxiety has two effects on the central executive component of the working memory system. First, it consumes attentional capacity through worry. When attentional capacity is consumed to the extent that no auxiliary resources remain to retain on-task attention, performance is impaired. Second, it increases effort. Increased effort can enhance performance by mobilizing auxiliary processing resources that increase the amount of attention devoted to a task. A key distinction is made between performance effectiveness (i.e., the quality of performance) and efficiency (i.e., effectiveness divided by expended effort). As performance can be maintained by compensatory increases in effort, anxiety is proposed to impair efficiency more than effectiveness.

To examine processing efficiency theory, Wilson, Smith and Holmes (2007) measured anxiety, effort, and golf putting performance during comparatively low and high levels of competitive pressure. They found performance effectiveness was maintained during high pressure. It was suggested that increased effort allowed performance effectiveness to be maintained despite increased anxiety in the high-pressure condition. However, as greater effort was required to achieve the same level of performance in the high-pressure condition as was achieved in the low-pressure condition, processing efficiency was reduced. This conclusion is compatible with the account of maintained performance that is offered by processing efficiency theory. Several studies provide similar support for processing efficiency theory (for review see Wilson, 2008). However, the hypothesised mediating roles of anxiety and effort on performance have yet to be formally confirmed (cf. Cooke, Kavussanu, McIntyre & Ring., in press).

Reinvestment Theory

An alternative psychological description of changes in motor performance under competitive pressure is offered by reinvestment theory (Masters & Maxwell, 2008). It suggests that increased anxiety directs attention inward (cf., Baumeister, 1984). This can cause skilled individuals to *reinvest* explicit knowledge of components of the movement that they are required to perform, and in doing so, take conscious control of their actions. Based on skill acquisition theories – which propose that when learning a skill, the cognitive demands start off as conscious and eventually become autonomous (e.g., Fitts & Posner,

1967) – reinvestment theory proposes that a reinvestment of task-relevant knowledge to explicitly control motor performance disrupts the automaticity of experts. This has a detrimental effect on performance because reverting to a more conscious mode of processing represents a regression to an earlier and less effective stage of movement control (Masters & Maxwell, 2008).

Studies that adopt dual-task paradigms to consciously draw the attention of experts to performance processes demonstrate that this reduces automaticity and thereby impairs performance (e.g. Beilock, Carr, MacMahon & Starkes, 2002; Gray, 2004). However, research has yet to demonstrate that competitive pressure causes reinvestment of explicit knowledge and thus a more conscious mode of movement control. Cooke et al. (in press) found competitive pressure to increase mental effort, which was partially responsible for impaired golf putting performance. If mental effort reflects conscious processing, then this finding would be supportive of reinvestment theory, but the relationship between mental effort and conscious processing is not known. Moreover, Cooke et al. (in press) only recruited novice golfers, who would be expected to be at the cognitive stage of skill acquisition, and thus have little room to regress under pressure to an earlier mode of control. A more appropriate measure of conscious processing needs to be taken from a sample of experts in order to comprehensively examine the account of pressure-induced changes in performance that is outlined by reinvestment theory.

Physiological Effects of Pressure

It is well documented that competitive pressure also elicits effects at a physiological level (e.g. Harrison, Denning, Easton, Hall, Burns et al., 2001). Cardiovascular measures can reflect emotional and motivational processes such as anxiety and effort (e.g., Kreibig, 2010; Mulder, 1992), and accordingly, could be used to examine processing efficiency theory. For example, Veldhuijzen van Zanten, De Boer, Harrison, Ring, Carroll et al. (2002) found that competitive pressure increased heart rate, which can reflect an increase in anxiety and/or arousal (e.g., Woodman & Davies, 2008). Specifically, increased anxiety can be reflected by increased heart rate which occurs with an increase in sympathetic activation, as part of the anxiety response (Kreibig, 2010). Veldhuijzen van Zanten et al. (2002) also found that competitive pressure decreased heart rate variability, which can reflect increased mental effort (Mulder, 1992). Specifically, increased mental effort can be reflected by decreased heart rate variability in the mid-frequency band (i.e., 0.07- 0.14 Hz) of the heart rate spectrum (Mulder, 1992), indicative of increased sympathetic and decreased parasympathetic cardiac control (Iani, Gopher & Lavie, 2004).

Such changes in autonomic regulation, which might indicate increased anxiety and effort, have been observed during competition (Harrison et al., 2001; Veldhuijzen van Zanten, et al., 2002). However, recent golf putting studies have failed to show a decrease in heart rate variability under pressure, despite increased self-reported effort, in novice (Cooke et al., in press) and experienced golfers (Mullen et al., 2005; Wilson et al., 2007). These findings could be due to the metabolic demands of the putting task overriding the effects of mental processes on cardiovascular responses. As experts display more efficient movements than those who are less skilled (Sparrow, 1983), their cardiovascular responses to competitive pressure are less likely to be confounded by metabolic demands. Accordingly, an examination of the effects of pressure on the cardiovascular activity of expert golfers could provide important insights into the effects of competitive pressure on mental processes, as well as corroborative physiological evidence for processing efficiency theory.

In addition to eliciting cardiovascular responses, competitive pressure has also been shown to increase muscle tension (cf. Fridlund & Cacioppo, 1986). This could directly account for some of the effects of pressure on motor performance (e.g., Cooke et al., in press). In the classic study by Weinberg and Hunt (1976), anxiety and electromyographic activity were measured while participants threw a tennis ball at a target. Performance, assessed by throwing accuracy, improved with increased pressure in participants low in anxiety, but did not change in those high in anxiety. Further, the high anxious participants contracted their agonist (biceps) and antagonist (triceps) muscles for longer than the low anxious participants, indicating reduced neuromuscular efficiency with elevated anxiety and pressure. Similarly, increased muscle activity was partially responsible for impaired performance under pressure in a golf putting task (Cooke et al., in press).

In golf putting, a key function of the muscles is to help appropriately grip the club, so increased muscle tension could make the performer grip the club more tightly. In support of this suggestion, Smith, Malo, Laskowski, Sabick, Cooney et al. (2000) reported higher grip forces and increased forearm muscle activity in golfers that were prone to impaired performance under competitive pressure, compared to those who reported being robust under pressure. However, the effects of pressure on grip force have yet to be experimentally examined.

Kinematic Effects of Pressure

Competitive pressure also elicits effects on the kinematics of movement (e.g. Pijpers, Oudejans, & Bakker, 2005). Changes in movement kinematics could reflect variations in conscious processing (e.g., Maxwell, Masters, & Eves, 2003), and accordingly, could be used to examine reinvestment theory. For example, Maxwell et al. (2003) analysed movement kinematics in a study of golf putting. A one-dimensional analysis of the kinematics of the back and forth movement of the club indicated that less accurate putting under conditions where demands on working memory resources were high (as occurs when one is anxious) was associated with increased jerkiness and decreased smoothness during the downswing (Maxwell, Masters, & Eves, 2003). This could reflect inefficiency and a reinvestment-induced regression to a more novice like stage of movement.

More recently, Cooke et al. (in press) uncovered a novel kinematic explanation of missed putts under pressure, in novice golfers. They conducted a three-dimensional kinematic analysis that allowed them to find pressure increased lateral clubhead acceleration thereby causing more putts to be pushed and pulled wide of the hole. However, the kinematics of the clubhead during golf putts differ among experts and novices. For example, Delay, Nougier, Orliaguet and Coello (1997) reported that downswing amplitude is greater, but impact velocity is less, for experts compared to novices. As a consequence, it is not known whether the mechanism highlighted by Cooke et al. (in press) will also hold for expert performance.

Summary of Previous Research

The literature reviewed above suggests that competitive pressure may exert effects on performance through a variety of pathways, by producing changes in psychological (e.g., anxiety, effort), physiological (e.g., muscle activity) and kinematic (e.g. acceleration) variables. Although several studies have assessed psychological, physiological, and movement-related effects of pressure in isolation, few studies have assessed them simultaneously. Moreover, only one study (Cooke et al., in press) has applied mediation analyses to examine causal mechanisms (cf., Wilson, Chattington & Marple-Horvat, 2008). A multi-disciplinary approach should provide fuller insights into the mechanisms that underlie changes in performance under pressure in sport (Pijpers, et al., 2005).

Finally, previous golf putting studies have examined the effects of competitive pressure on the performance of novices (e.g., Cooke et al., in press) and experienced golfers (e.g., Wilson et al., 2007) but none have examined experts. Previous research (e.g., Gray, 2004) has demonstrated that the mechanisms which drive expert performance under pressure differ from those that explain novice performance. Accordingly, a study which adopts a multi-disciplinary approach to investigate the effects of competitive pressure on experts is warranted.

The Present Study

The present study aimed to concurrently examine the performance of expert golfers, and their psychological, physiological and kinematic responses to competitive pressure. Based on the literature described above, it was hypothesized that pressure would elicit increases in anxiety, effort, conscious processing, heart rate, muscle activity and grip force. Moreover, pressure was expected to decrease heart rate variability and disrupt movement kinematics. The primary purpose was to examine whether increased competitive pressure is associated with changes in performance and to formally evaluate possible causes using mediation analyses. Processing efficiency theory predicts that effort should mediate performance, if it improves with pressure, and anxiety should mediate performance, if it deteriorates with pressure. Alternatively, reinvestment theory predicts that conscious processing should mediate performance, if it deteriorates with pressure. Finally, it was hypothesized that neuromuscular, grip force and kinematic changes would prove additional mediators of performance if it was impaired with increased pressure.

Method

Participants

Male (n = 44) and female (n = 6) right-handed expert golfers (M = 20.3, SD = 1.5 years old) gave informed consent and volunteered to participate in the experiment. Their mean experience playing golf was 7.81 (*SD* = 2.98) years and their mean handicap was 3.01 (*SD* = 2.21). The handicap represents the number of shots taken above the expected number of shots for each round of golf; such that, the lower the handicap, the better the player. These data establish the expertise of the current sample of players.

Equipment

A standard length (90 cm) steel-shafted blade style golf putter (Scotty Cameron Circa 62, Titleist, Fairhaven, MA) was used to putt regular-size (diameter = 4.27 cm) golf balls (Pro V1, Titleist) towards a half-size hole (diameter = 5.5 cm; depth = 1.3 cm), used to increase the accuracy demands of the task. The hole was located 0.75 m from the end and 0.7 m from the side of a 6.25 m long × 1.4 m wide strip of a green putting mat (Patiograss). The putting surface had a Stimpmeter reading of 4.27 m, making it faster than the greens at most American golf courses, which, according to the US Golf Association (n.d.), generally range from 2.13 m to 3.66 m.

Design

This experiment employed pressure condition as a within-subjects factor, with three levels: low, medium, and high. Participants completed five blocks of six putts. The first two blocks helped acclimatization with the task demands, whereas blocks three, four and five represented comparatively low, medium, and high-pressure conditions, respectively.

Performance Measures

Both the number of putts successfully holed and mean radial error (i.e., the mean distance of the balls from the hole) were recorded as measures of performance (Mullen & Hardy, 2000). Zero was recorded and used in the calculation of mean radial error on trials where the putt was holed (Hancock, Butler, & Fischman, 1995).

Psychological Measures

Anxiety. Anxiety was measured using the 5-item cognitive anxiety subscale of the Competitive State Anxiety Inventory-2 Revised (Cox, Martens, & Russell, 2003). Participants were asked to indicate how they felt while putting in relation to each item, for example "I was concerned about performing poorly" and "I was concerned about choking under pressure". Each item was scored on a 4-point Likert scale (1 = *not at all*, 2 = *somewhat*, 3 = *moderately so*, 4 = *very much so*). The item responses were averaged and multiplied by ten to provide one score for the subscale. Cox et al. (2003) reported a reliability coefficient of .83 for cognitive anxiety, showing a good level of internal consistency. In this experiment, alpha coefficients across the three pressure conditions were good or very good (.77 to .90).

Effort. Effort was measured using the Rating Scale for Mental Effort (Zijlstra, 1993). Participants were instructed to rate the level of mental effort that they expended using a vertical axis scale ranging from 0–150, with nine category anchors, including, at the extremes, 3 (*no mental effort at all)* and 114 *(extreme mental effort)*. The scale has good test-retest reliability, with a correlation coefficient of .78 (Zijlstra, 1993), and has been used to assess mental effort in sport (e.g., Wilson et al., 2007). In this experiment, the correlation coefficients among the three pressure conditions ranged from .64 to .87.

Conscious processing. The conscious motor processing subscale of the Movement Specific Reinvestment Scale (Orrell, Masters & Eves, 2009) was adapted to assess conscious processing while putting. Participants were asked to indicate how they felt while putting in relation to six items, for example "I thought about my stroke" and "I was aware of the way my body was working". Each item was scored on a 5-point Likert scale, with anchors of 1 (*never*), 3 (*sometimes*) and 5 (*always*). Responses were averaged to provide a score for the scale. The internal consistency of the measure was very good (.81 to .86) across the three pressure conditions.

Physiological Measures

Cardiac activity. To assess heart rate and heart rate variability, an electrocardiogram was measured using three silver/silver chloride spot electrodes (Cleartrace, ConMed, Utica, NY) in a modified chest configuration. The electrocardiographic signal was amplified (Bagnoli-4, Delsys, Boston, MA), filtered (1–100 Hz), and digitized at 2500 Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK) using Spike2 software (Cambridge Electronic Design). Heart rate and a time domain index of heart rate variability (SDNN) for each condition were derived from the intervals between R-waves of the electrocardiogram. SDNN (standard deviation of R-R intervals) is a correlate of the 0.04 – 0.15 Hz frequency domain based spectral power band, $r = .84$, $p <.0001$ (Carrasco, Gaitan, Gonzalez & Yanez, 2001), which includes the 0.07 – 0.14 Hz component that Mulder (1992) considers to be sensitive to variations in effort. The time domain correlate of the frequency band was assessed due to the brevity of each recording epoch (block of putts, low pressure $M = 132$ s, $SD = 20$ s, medium pressure $M = 138$ s, $SD = 27$ s, high pressure $M = 158$ s, $SD = 32$ s), which, coupled with slow heart rates of some participants, left insufficient R-R intervals to perform spectral analyses. The analogue electrocardiographic signals were scored using an interactive program which identified peaks that were then visually inspected to confirm correct identification of the R-wave, and, if necessary, moved manually. Participants were asked to remain as still as possible and refrain from talking in between the putts in each recording block. This largely eliminated the need for manual artefact correction.

Muscle activity. Electromyographic activity of the extensor carpi radialis, flexor carpi ulnaris, and deltoid muscles of the left arm was recorded; these muscles were chosen based on previous studies (Smith et al., 2000; Stinear, Coxon, Fleming, Lim, Prapavessis & Byblow, 2006) and pilot testing that implicated them in the putting stroke. Muscle activity was measured using single differential surface electrodes (DE 2.1, Delsys) and an amplifier (Bagnoli-4, Delsys) with a ground electrode on the collar bone. Electromyographic signals were amplified, filtered (20-450 Hz) and digitized (2500 Hz).

The electromyographic signal for each trial was rectified and the mean amplitudes (microvolts) were calculated by averaging the activity over four consecutive periods: pre-initiation baseline, upswing, downswing, post-contact follow-through. The duration of these periods was calculated from the Z-axis acceleration profile (described below). The upswing lasted from movement initiation until the top of the swing; the duration of the pre-initiation baseline was the same as the duration of the upswing. The downswing lasted from the top of the swing until ball contact; the duration of the post-contact follow-through was the same as the duration of the downswing. The trial values in each condition were averaged to provide a condition mean value for each electromyographic variable.

Grip force. Grip force was recorded by two strain gauges on the shaft of the putter (see Radwin, Masters & Lupton, 1991). All participants were right-handed and adopted the standard left above right hand grip. Each gauge was positioned to correspond with their right and left hand placements. Force data were acquired through a Power 1401 (Cambridge Electronic Design) after being amplified (× 500), filtered (0 – 300 Hz) and digitised (2500 Hz). The grip force for each trial was also calculated by averaging the activity over pre-initiation baseline, upswing, downswing, and post-contact follow-through swing phases.

Kinematic Measures

Acceleration of the clubhead in three axes was recorded using a tri-axial accelerometer (LIS3L06AL, ST Microelectronics, Geneva, Switzerland). Acceleration on the

X, Y and Z axes corresponded to lateral, vertical and back-and-forth movement of the clubhead, and assessed clubhead orientation, clubhead height, and impact velocity, respectively. The signals were conditioned by a bespoke buffer amplifier with a frequency response of DC to 15 Hz. Both accelerometer and amplifier were mounted in a 39 mm × 20 mm × 15 mm plastic housing secured to the rear of the putter head. A microphone (NT1, Rode, Silverwater, Australia) connected to a mixing desk (Club 2000, Studiomaster, Leighton Buzzard, UK) was used to detect the putter-to-ball contact on each trial. These signals were digitized at 2500 Hz. A computer program determined movement kinematics for each putt from the onset of the downswing phase of the putting stroke until the point of ball contact. The average acceleration was calculated for the X, Y and Z axes. Impact velocity, root mean square (RMS) jerk and smoothness were also calculated for the Z axis as the primary axis involved in putting (see Maxwell et al., 2003). The values from the six trials in each condition were averaged to provide a condition mean value for each kinematic variable.

Manipulations

Based on Baumeister and Showers' (1986) research concerning the additive psychological factors that produce pressure (e.g., competition, rewards, social evaluation), comparatively low, medium, and high-pressure conditions were created.

Low-pressure. Participants were informed that the first three blocks of putts were part of a study to compare putting with a black-and-white ball versus a standard white ball. In block one, participants putted a standard white ball on odd-numbered trials and a black-and-white ball on even-numbered trials. In block two, they putted only a black-and-white ball. In block three, they putted only a white ball. To encourage participants to take the same approach to putting as golfers, prior to putting in each block they were asked to "try and get the ball ideally in the hole, but if unsuccessful, to make it finish as close to the hole as possible". It was further explained that performance would to be recorded as the average distance that putts finished from the hole, with any holed putts counting as 0 cm. However, to minimize any pressure that may have been elicited by evaluation from the experimenter, participants were told that although the distance that each putt finished from the hole would be recorded, individual performance would not be analyzed in this condition. Instead, they were informed that the data from all participants would be pooled to generate one accuracy score for the black-and-white ball and one accuracy score for the white ball. In reality, the painted and standard balls were not compared; this part of the experiment was designed to minimise any pressure elicited by evaluation. Data from block three constituted the low-pressure condition.

Medium-pressure. The fourth block of putts constituted the medium-pressure condition. Prior to beginning this condition, participants were told that the next *two* blocks comprised the competition phase of the study. They were informed that, from now on, their performance would be compared with the performance of the other participants, through a team competition. To emphasize the evaluative nature of this condition, participants were told that the rank-ordered performances of each team would be displayed on a noticeboard and e-mailed to all participants. The team to which each participant was allocated was based on their university course and year group: 1st year golf degree students, 2nd year golf degree students, 3rd year golf degree students, sport science degree students. These teams were expected to increase inter-year and inter-course rivalry. Moreover, the nature of the teams ensured that participants were familiar with their team mates, and as such, there was an emphasis on not letting others down. Participants were informed that every individual performance would contribute to the overall team average, which was the average distance from the hole of all putts made by participants in each team. They were reminded again that, ideally, they should try and get the ball in the hole, because holed putts count as 0 cm in calculating the mean radial error performance score. If unsuccessful, they were told to try to make the ball finish as close to the hole as possible. Given that evaluative conditions with financial incentives have been used previously to induce pressure (e.g., Wilson et al., 2007), participants were told that all members of the winning team would be entered into a raffle and a cash prize of £20 would be awarded to the winner. Finally, they were made aware that each team comprised "about ten" other participants to allow them to evaluate their chances of winning.

High-pressure. The fifth block of putts comprised the high-pressure condition. To further increase pressure an individual competition offering greater rewards was introduced. Participants were told that: (a) in addition to the on-going team competition, their performance in this final block of putts would be directly compared with the performance of the other participants; (b) the rank-ordered performances of the whole sample would be displayed on a noticeboard and e-mailed to all participants; and (c) cash prizes of £100, £50, and £10 would be awarded to the top three performers at the end of the study. It was again emphasized that they should try and get the ball ideally in the hole to give them the best chance of winning, and if unsuccessful, they were to try to make the ball finish as close to the hole as possible. Participants were made aware that they would be competing against "about fifty" other participants to allow them to evaluate their chances of success. To increase self-awareness, a video camera (Sony, Tokyo, Japan), fitted with a wide-angled lens and light, was turned on (Buss, 1980). The camera was prominently positioned adjacent to the participant, and explicitly turned on and off before and after each putt.

Manipulation Check

To check the effectiveness of the experimental manipulations in creating multiple levels of pressure, participants completed the written 5-item pressure/tension subscale from the Intrinsic Motivation Inventory (Ryan, 1982). Participants were asked to rate items, including “I felt pressured” and “I felt very tense” on a 7-point Likert scale (*1= not at all true, 4= somewhat true, 7= very true*). The item responses were averaged to provide one score for the scale. McAuley, Duncan, and Tammen (1989) reported an internal consistency of .68 for this subscale. In this experiment, the Cronbach’s alpha coefficient in the low-pressure condition was low (.55). Removal of the negatively scored item “I did not feel nervous” improved the internal consistency across conditions to an acceptable level (.66 to .90). Thus, the pressure scores were computed without this item.

Procedure

The protocol was approved by the local research ethics committee. First, participants were instrumented to allow the recording of physiological measures. Then, they completed a putting task comprising five blocks of six putts. Putts were made from three distances to reduce familiarity with one particular distance (see Wilson et al., 2007). The same counterbalanced order of putting distances was fixed for each block: 1.8, 1.2, 2.4, 2.4, 1.2 and 1.8 m. The first two blocks served to acclimatize participants with the task. The last three blocks represented the experimental conditions: low-pressure (block three), medium-pressure (block four), and high-pressure (block five). The order of these conditions was fixed to minimize threats to validity (e.g., reduced motivation during low-pressure) when high-pressure precedes low-pressure (Beilock & Carr, 2001). Moreover, fixing the order of conditions also enhanced the ecological validity of the experimental manipulation, because golfers commonly report experiencing the greatest pressure during the final few putts of their round.

Prior to putting in each of the three pressure conditions, the manipulation took place. Putting followed, and immediately after the final putt of each condition, retrospective measures of pressure, effort, anxiety and conscious processing were obtained. Physiological measures were recorded continuously during each block. Successful putts were recorded immediately on a data sheet. The position of any unsuccessful putt was marked by placing a sticker on the mat. The ball then was retrieved by the experimenter and placed at the next position. At the end of each block, the distance of each marker from the hole was recorded and the marker was removed from the mat.

At the end of the session participants were questioned regarding any ball preference (i.e., white versus black-and-white). Their answers indicated that the low-pressure manipulation was credible; none guessed that this part of the experiment was not the true purpose of the study. They were then thanked and debriefed. At the end of the experiment, the leaderboards were displayed and the top three performers plus the team raffle winner were paid their prize money.

Statistical Analysis

First, a Multivariate Analysis of Variance (MANOVA) was conducted to examine the effects of pressure condition (low, medium, high), the within-subjects factor, on the performance, psychological, cardiac and kinematic variables. This revealed a significant multivariate effect for pressure condition, $F(28, 17) = 9.44$, $p < .001$, $\eta_p^2 = .94$. Next, MANOVA was used to examine the effects of pressure condition and swing phase, both within-subject factors, on muscle activity and grip force. This 3 pressure condition × 4 swing phase (pre-initiation, upswing, downswing, post-contact) MANOVA yielded significant multivariate effects for condition, $F(10, 39) = 2.71$, $p < .05$, $\eta_p^2 = .41$, and phase, $F(15, 34) = 15.42$, $p < .001$, $\eta_p^2 = .87$.

To probe these effects, separate repeated measures Analyses of Variance (ANOVAs) were conducted, followed by polynomial trend analyses and least significant difference (LSD) post-hoc comparisons, on each variable. These analyses, as well as mediation analyses, which were conducted next, are presented in the results section. Analyses of Covariance (ANCOVA) were used to examine mediation (see Cooke et al., in press). ANOVA and ANCOVA produce identical results to and are conceptually equivalent to regression analyses (Cohen, Cohen, West, & Aiken, 2003).

The multivariate method for reporting results was used. This method minimizes the risk of violating sphericity and compound symmetry assumptions in repeated measures ANOVA designs (Vasey & Thayer, 1987); its use can be identified by the reduced degrees of freedom reported. Wilks' lamda, the multivariate statistic (which is not reported), equals $1 - \eta_p^2$. Partial eta-squared (η_p^2) is reported as the effect size. In ANOVA this equals the adjusted R^2 obtained in regression analyses (Tabachnick & Fidell, 2001), and values of .02, .13 and .26 indicate relatively small, medium and large effect sizes, respectively (Cohen, 1992).

Results

Manipulation Check

A 3 pressure condition (low, medium, high) ANOVA confirmed a main effect for pressure condition on the perceived pressure associated with each block of putts $F(2, 48) = 38.89$, $p < .001$, $\eta_p^2 = .62$. As expected, the polynomial trend was linear; perceived pressure increased in a linear fashion from low-pressure ($M = 2.23$, $SD = 0.77$) to medium-pressure ($M = 2.91$, $SD = 1.22$) to high-pressure ($M = 3.66$, $SD = 1.39$) conditions.

Effects of Pressure on Performance

The effects of the pressure manipulation on putting performance are illustrated in Figure 3.1. Separate ANOVAs revealed a pressure condition main effect for mean radial error, $F(2, 48) = 3.46$, $p < .05$, $\eta_p^2 = .13$, but not for the number of balls holed, $F(2, 48) = 1.57$, $p = .22$, $\eta_p^2 = .06$. A linear trend was evident, where mean radial error was smaller during medium-pressure and high-pressure than during low-pressure (Figure 3.1A), however, this pattern was not due to more putts being holed with increased pressure (Figure 3.1B). Indeed, balls holed displayed a quadratic pattern.

Effects of Pressure on Psychological Measures

ANOVAs revealed main effects of pressure condition for anxiety, effort, and conscious processing (see Table 3.1). Anxiety and effort displayed linear increases with increased pressure, whereas conscious processing displayed a quadratic trend, with least conscious processing during the medium-pressure condition.

Effects of Pressure on Physiological Measures

ANOVAs indicated a main effect of pressure condition for heart rate, which increased primarily in a linear fashion from low to high-pressure conditions, and left-handed grip force, which decreased linearly from low-pressure to high-pressure. Right-handed grip force showed a linear trend in the opposite direction, where grip force increased with more pressure. No effects of pressure condition were evident for heart rate variability or muscle activity. The condition effects are presented in Table 3.1.

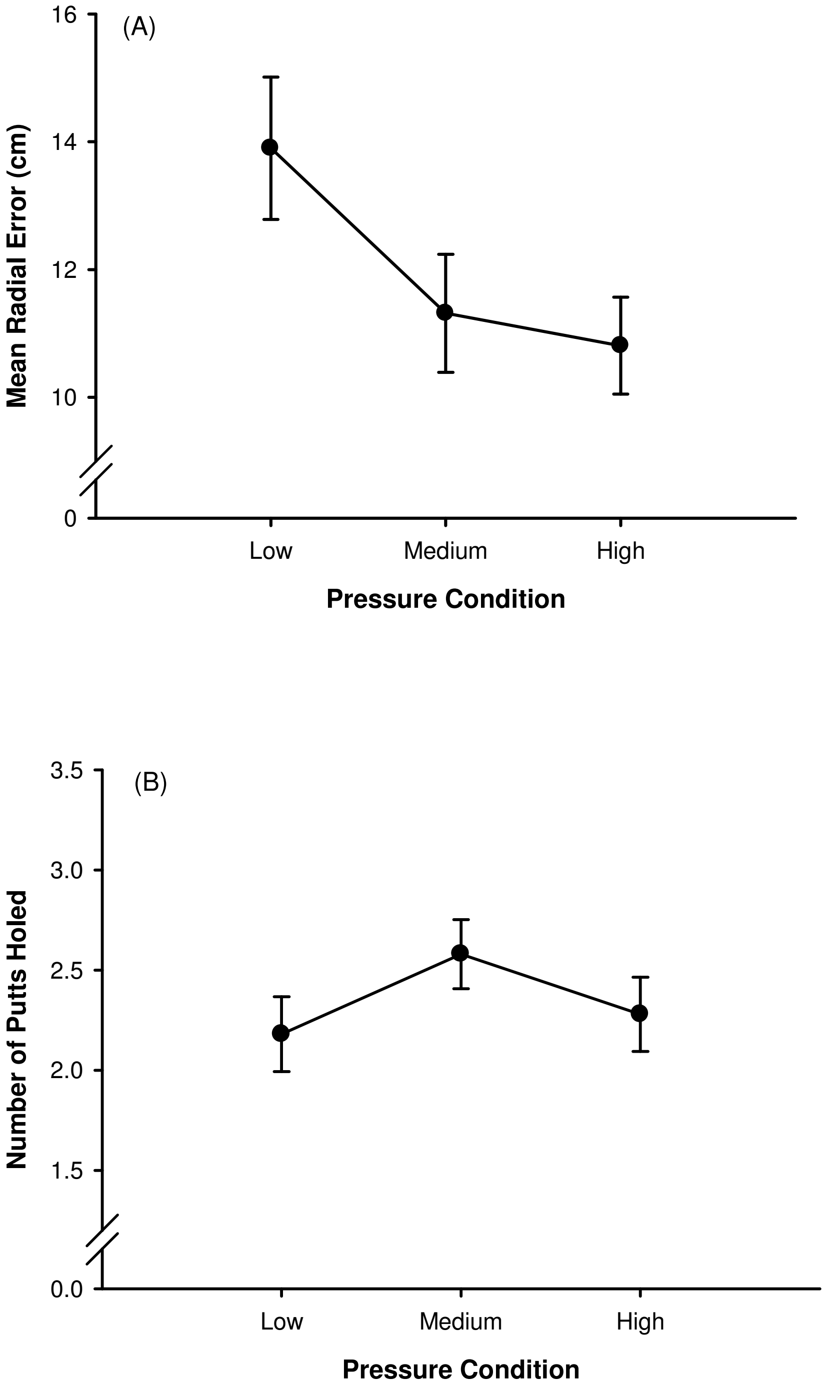

Figure 3.1. (A) Mean radial error scores across pressure conditions. (B) Number of balls successfully holed across pressure conditions. Error bars depict standard error of the means.

Table 3.1: *Mean (SD) of the Measures in each Pressure Condition*

Measure (range of scores possible)	Pressure Condition						*F* (2, 48)	η_p^2
	Low		Medium		High			
	M	*SD*	*M*	*SD*	*M*	*SD*		
Psychological								
Anxiety (10-40)	17.09	5.24	18.97 ^{a}	7.14	20.36 ^{a,b}	7.71	6.97**	.23
Effort (0-150)	70.12	20.21	84.02 ^{a}	18.50	93.38 ^{a,b}	17.17	58.97***	.71
Conscious processing (1-5)	2.95	0.87	2.63 ^{a}	0.90	2.80 ^{b}	0.99	7.95***	.25
Physiological							*F* (2, 47)	
Heart rate (bpm)	89.63	13.00	92.91 ^{a}	15.03	99.38 ^{a,b}	17.37	27.79***	.54
SDNN (ms)	70.72	23.65	71.52	23.97	69.23	24.06	0.48	.02
Extensor carpi radialis EMG (μV)	21.05	11.06	20.88	11.77	20.47	11.33	0.42	.02
Flexor carpi ulnaris EMG (μV)	16.01	11.14	15.50	11.50	14.97	10.83	2.17	.09
Deltoid EMG (μV)	3.38	2.56	3.45	3.00	3.35	2.45	0.71	.03
Left hand grip force (N)	24.81	12.94	23.70 ^{a}	12.50	23.79 ^{a}	13.22	5.44**	.19
Right hand grip force (N)	17.78	9.83	17.95	9.85	18.55	10.02	2.64	.10
Kinematic							*F* (2, 43)	
X-axis acceleration ($m.s^{-2}$)	0.30	0.13	0.30	0.14	0.30	0.15	0.15	.01
Y-axis acceleration ($m.s^{-2}$)	0.45	0.13	0.45	0.15	0.44	0.16	0.59	.03
Smoothness	80.44	14.85	81.16	15.02	80.04	15.35	1.11	.05

Note: Letters (a and b) indicate significant difference from low and medium-pressure conditions respectively. *p <.05, **p <.01, ***p <.001. Kinematic and physiological data were unscorable for five participants and one participant, respectively; missing data are reflected in the reported degrees of freedom.

The 3 condition × 4 phase ANOVAs also revealed main effects for swing phase on both muscle activity and grip force. Polynomial analyses indicated linear and quadratic changes from the pre-initiation to post-contract phases of the swing (see Table 3.2). Finally, analyses yielded no interaction effects.

Effects of Pressure on Kinematic Measures

ANOVAs revealed a significant effect of pressure condition on impact velocity, $F(2, 43) = 3.23$, $p < .05$, $\eta_p^2 = .13$, and marginally significant effects of pressure condition on Z-axis acceleration, $F(2, 43) = 2.52$, $p = .09$, $\eta_p^2 = .11$, and RMS jerk, $F(2, 43) = 2.70$, $p = .08$, $\eta_p^2 = .11$. Polynomial analyses confirmed that these were all significant quadratic trends. Figure 3.2 illustrates that in the medium-pressure condition the putter was swung more slowly and less jerkily in the primary back-and-forth axis, and accordingly, the impact velocity was smaller, when compared to the low-pressure condition. Finally, no effects of pressure condition were found for lateral and vertical clubhead acceleration or smoothness of movement (see Table 3.1).

Mediation Analysis

Mediation analyses were employed to test whether any of the psychological, physiological or kinematic variables mediated the significant improvement in putting performance, indicated by the reduced mean radial error in the medium-pressure and high-pressure conditions compared to the low-pressure condition. To establish mediation, four criteria must be satisfied (Baron & Kenny, 1986). First, the independent variable must affect the dependent variable. The main effect of pressure condition on mean radial error satisfied this criterion. Second, the independent variable must affect the mediator. Effects of pressure condition were evident in all psychological variables as well as heart rate, grip force applied by the left hand, and impact velocity, satisfying this criterion. The final two criteria are that

Table 3.2: *Mean (SD) of EMG Activity and Grip Force during each Swing Phase*

	Swing Phase									
Measure	Pre-initiation baseline		Upswing		Downswing		Post-contact		*F*(3, 46)	η_p^2
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Extensor carpi radialis EMG (μV)	15.07	8.73	20.47[a]	10.53	25.36[a,b]	14.72	22.30[a,b,c]	12.58	25.05***	.62
Flexor carpi ulnaris EMG (μV)	13.19	13.19	15.25[a]	11.59	16.68[a,b]	11.81	16.87[a,b]	11.31	10.28***	.40
Deltoid EMG (μV)	2.89	0.87	3.00	1.24	3.71	4.54	3.99[b,c]	4.43	5.58**	.27
Left hand grip force (N)	17.34	10.39	24.68[a]	12.84	26.80[a,b]	14.54	27.58[a,b,c]	14.29	52.76***	.78
Right hand grip force (N)	12.17	7.44	17.64[a]	8.99	21.36[a,b]	12.22	21.21[a,b]	11.99	42.03***	.73

Note: Letters (a, b and c) indicate significant difference from pre-initiation baseline, upswing and downswing phases respectively. ***p* <.01, ****p* <.001

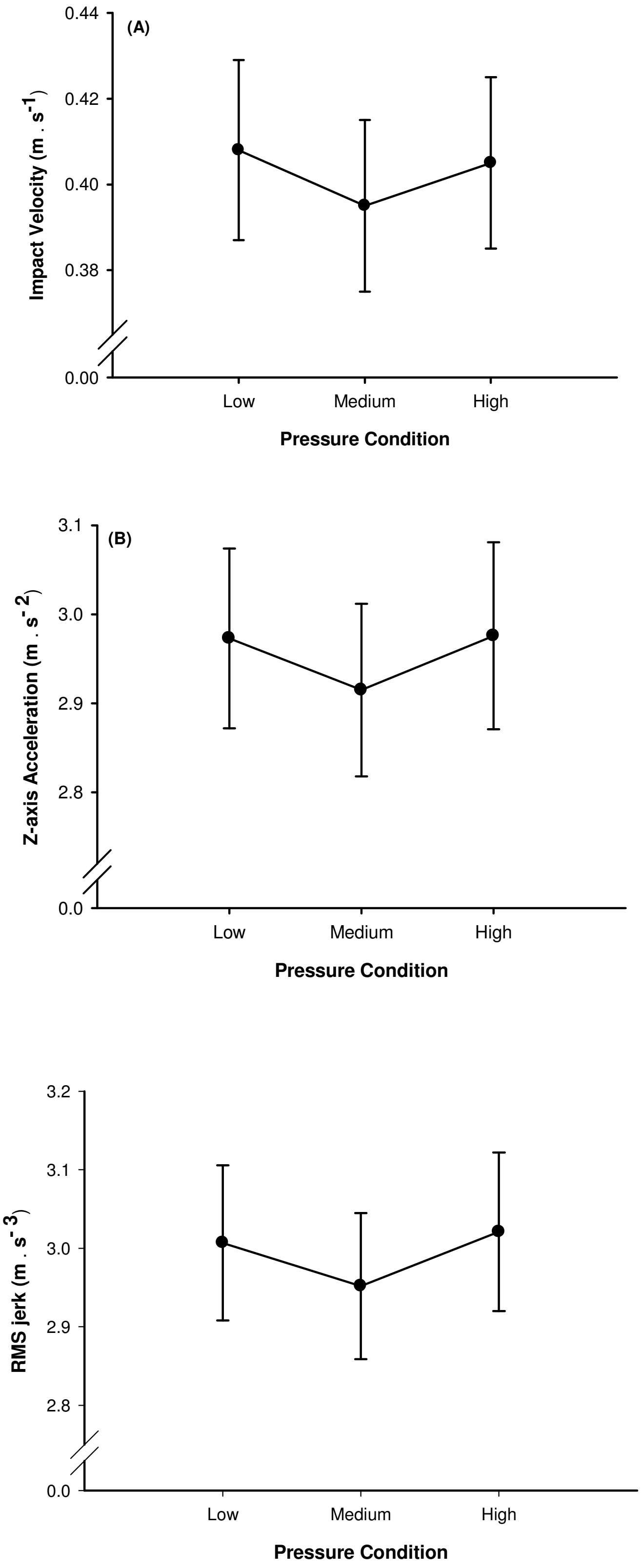

Figure 3.2. A) Impact velocity across each pressure condition. B) Z-axis acceleration across each pressure condition. C) Root mean square jerk across each pressure condition. Error bars depict standard error of the means.

the mediator must affect the dependent variable and that the effect of the independent variable on the dependent variable must be reduced in the presence of the mediator. Any variables that satisfy these final criteria can be considered mediators of the observed improvement in performance under pressure. The change in η_p^2 associated with the pressure condition when each variable is used as a covariate indicates the importance of that variable in explaining the effects of pressure condition on putting performance (see Tabachnick & Fidell, 2001).

Accordingly, repeated measures ANCOVA, with each potential mediator variable as the changing covariate and pressure condition as a within-subjects factor, were conducted to simultaneously test whether the last two criteria were met. The original analysis indicated that 13% of the variance in mean radial error could be attributed to pressure condition; this corresponds to a medium size effect for pressure on performance. This effect did not survive the covariate adjustment for effort, $F(2, 46) = 1.72$, $p = .19$, $\eta_p^2 = .07$, or heart rate, $F(2, 45) = 0.74$ $p = .48$, $\eta_p^2 = .03$, indicating that these variables partially mediated the effect of pressure on performance[1]; mediation was partial as a small-to-medium effect size remained. In sum, mediation analyses indicated that improved putting performance under pressure was explained in part by changes in psychological and physiological processes.

Discussion

To help understand the mechanisms of pressure-induced changes in performance, this study concurrently examined performance, psychological, physiological and kinematic

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[1] As effort mediated performance, ANCOVA was also employed to examine whether effort was mediated by anxiety, as would be predicted by processing efficiency theory. The original analysis indicated that 71% of the variance in effort could be attributed to pressure condition. This effect survived the covariate adjustment for anxiety, $F(2, 46) = 53.23$, $\eta_p^2 = .70$, providing no evidence for this theoretical prediction.

responses to multiple levels of competitive pressure. Building on previous research (e.g., Cooke et al., in press), it examined an expert population, and formally tested potential mechanisms to explain the pressure–performance relationship. Manipulation checks confirmed that ratings of pressure were greatest in the high-pressure condition and smallest in the low-pressure condition. Accordingly, the manipulations were successful in pressuring participants, as per real-life sporting competition (cf., Baumeister & Showers, 1986).

Effects of Pressure on Performance

Results showed that competitive pressure had a clear positive effect on performance reflected by the accuracy measure, mean radial error: Putts finished closer to the hole under medium and high-pressure conditions than during low-pressure. This finding is consistent with some (e.g., Koedijker, Oudejans & Beek, 2008) but not all (e.g. Wilson et al., 2007) studies that have included accuracy measures of performance. In terms of the outcome measure, number of putts holed, pressure had no clear effect on performance. This finding is also consistent with some (e.g., Mullen & Hardy, 2000) but not all (e.g., Cooke et al., in press) studies that have used outcome measures of performance. However, it may be worth noting that more putts tended to be holed during the medium-pressure than during the low-pressure condition (Figure 3.1B).

Accordingly, there was a discrepancy between the accuracy (i.e., mean radial error) and outcome (i.e., putts holed) measures of performance. It is possible that this discrepancy may be attributed to the use of a reduced-size hole. Specifically, this feature of the putting task imposed a stringent accuracy demand for putts to be holed, and thus, it may have been difficult to increase the number of balls holed under pressure. In contrast, tasks with less stringent accuracy demands (e.g. putting a ball close to a target, regardless of its size), do not appear to demand the same level of precision of movement to improve performance (e.g.

reduce mean radial error score) with increased pressure (cf., Cooke et al., in press). The mechanisms which underlie the observed effects of pressure on performance are discussed in the following sections.

Psychological Mediators of Performance

Based on processing efficiency theory (Eysenck & Calvo, 1992), it was hypothesised that pressure would increase anxiety and effort. These hypotheses were supported. Moreover, mediation analyses revealed that increased self-reported effort, but not anxiety, partially mediated the observed pressure-induced increase in putting accuracy. According to processing efficiency theory, increased effort improves performance by allocating additional attention to a task (Eysenck & Calvo, 1992). This is the first study to empirically demonstrate that effort can mediate improved performance.

Contrary to the next hypothesis and the predictions of reinvestment theory (Masters & Maxwell, 2008), conscious processing did not increase from low to high-pressure conditions. Instead, pressure affected the degree of self-reported conscious processing in a quadratic fashion. This finding could explain the trend for more putts to be holed during the medium-pressure condition. Specifically, more putts tended to be holed during medium pressure, when the amount of conscious processing during performance was lowest. This observation is in line with the skill acquisition models (e.g., Fitts & Posner, 1967) that underpin reinvestment theory, as more putts tended to be made when participants adopted a less conscious and thus more automatic information processing strategy. However, mediational analyses could not test this putative relationship due to the non-significant effect of pressure condition on number of putts holed (Baron & Kenny, 1986).

That conscious processing seems to resonate more with the outcome measure of performance than the accuracy measure could be due to the added precision of movement that is demanded in order to putt the ball into a reduced-size hole, rather than simply get it close (Cooke et al., in press). Perhaps fluctuations in conscious processing affect fine precision that more forgiving tasks (e.g. simply getting the ball close to the target) are less sensitive to. Specifically, increased effort permitted more balls to finish closer to the hole, but could not increase the number holed.

However, it is possible that processing efficiency theory could also explain the trend for more putts to be holed during medium pressure. Specifically, greater anxiety in the high-pressure condition could have overloaded attentional capacity thus causing performance to reduce from medium to high-pressure, despite increased effort. Alternatively, participants may have experienced more fatigue during the high-pressure condition, which could reduce the amount of attentional resources that were available. Although plausible, these explanations remain speculative, as an assessment of attentional capacity and resources is required for either to be confirmed.

Physiological Mediators of Performance

It was hypothesised that heart rate would increase with increased pressure, to reflect increased anxiety or arousal. Heart rate was increased, and mediation analyses revealed that this increase was in part responsible for the pressure-induced improvement in performance. This finding is contrary to the predictions of processing efficiency theory, which does not attribute improved performance to increased anxiety. Moreover, this relationship was absent in terms of self-reported anxiety. It seems likely therefore that heart rate was elevated by other factors in addition to an increased number of worrisome thoughts felt during increased pressure. It is possible that the increase in heart rate was driven by an increase in metabolic demands during medium and high-pressure conditions. However, no increase in muscle activity in the primary muscles that are responsible for the putting movement were observed (see below). This suggests that there were no extra metabolic demands during increased pressure. In contrast, it is possible that the increase in heart rate was driven by increased positive emotions such as enjoyment, engagement and excitement, that are often reported during competition (e.g., Tauer & Harackiewicz, 2004). For example, Blascovich, Seery, Mugridge, Norris, and Weisbuch (2004) suggest that an increase in heart rate and ventricular contractility represent task engagement. Unfortunately, no indices of contractility, or other measures of positive emotion, were assessed in the present study, and so this account remains speculative.

Heart rate variability, which has been proposed as a physiological indicator of invested effort (Mulder, 1992), was also assessed. Specifically, decreased heart rate variability in the 0.07 – 0.14 Hz spectral power band is a putative indicator of increased effort (Mulder, 1992). The results of this experiment indicated that pressure had no effect on SDNN, a correlate of heart rate variability in the 0.04 – 0.15 Hz band (Carrasco et al., 2001), which includes the mid-frequency component. Cooke et al. (in press) and Wilson et al. (2007) also did not observe any decrease in heart rate variability despite increased pressure and self-reported effort during golf putting. It seems that even when movement-efficient experts are recruited (Sparrow, 1983), the postural and physical demands of the golf putting task, although minimal, still override the effects of mental activity on cardiovascular measures (cf. Veldhuijzen van Zanten, Thrall, Wasche, Carroll, & Ring, 2005). These findings argue against the use of heart rate variability as a reliable measure of mental effort during sport.

The next hypothesis was that muscular and grip force changes would be affected by pressure and could account for changes in performance. In contrast to the findings of Weinberg and Hunt (1976), muscular activity was not augmented by increased pressure.

Results did confirm that each of the observed muscles was active during the putting stroke. As a consequence, the physical demands of the putting task may have overridden any potential effects of pressure on muscle tension.

In contrast, pressure did affect the grip force applied to the putter by the left hand, where the putter was gripped more lightly during increased pressure. Electromyographic data are notoriously variable across participants (e.g., Fridlund & Cacioppo, 1986), and as such, it seems that the measure of grip force was more sensitive to the effects of pressure than forearm muscle activity. It is plausible that lighter gripping under competitive pressure should improve putting performance, as it indicates more efficient, and permits less restricted, putter movements. However, mediation analyses did not establish such a mechanism. This is likely because lighter gripping by the left hand resulted in a trade off where more grip force was applied by the right hand during increased pressure in order to compensate (see Table 3.1). As the right hand should grip minimally in the traditional left above right hand putting grip that was adopted by participants (e.g., Pelz, 2000), increased grip force by this hand under pressure is unlikely to facilitate performance. This strategy rendered the grip force applied by expert golfers in the present study unrelated to performance.

Kinematic Mediators of Performance

Mediation analyses revealed that changes in movement kinematics were not responsible for improved putting accuracy with increased pressure. However, quadratic effects were noted for impact velocity, and acceleration and jerk on the primary back-and-forth axis of the swing, whereby the club was swung more slowly, less jerkily, and accordingly, the ball was struck with a lower velocity during medium pressure. This finding resonates with outcome performance, where more putts tended to be holed in the medium-pressure condition. However, as this effect was non-significant, the putative mechanistic accounts of this relationship could not be examined. These findings also sit well with the quadratic relationship that was observed for conscious processing. Specifically, participants reported engaging in less conscious processing during medium pressure, which was when the kinematics revealed a slower and less jerky swing that is a characteristic of experts compared to novices (Delay et al., 1997). Taken together with the performance measure of balls holed, and the measure of conscious processing, the quadratic kinematic effects also support the principles that underpin reinvestment theory. It seems that when participants demonstrated a more automatic, expert like, way of thinking (i.e., during medium pressure), they also swung the club more efficiently, and in doing so, tended to hole more putts.

An Integrative Perspective

Although the psychological, physiological and kinematic variables have been presented in separate sections, it was suggested previously that they could be related (e.g., Maxwell et al., 2003; Mulder, 1992). Accordingly, the physiological and kinematic variables could provide the mechanisms through which variations in processing efficiency or conscious processing exert their effects on performance. Little support was found for the suggested relationships between cardiovascular measures and anxiety and effort (e.g., Kreibig, 2010; Mulder, 1992), hence providing little corroborative physiological support for the predictions of processing efficiency theory. However, the quadratic effects that were noted for conscious processing as well as some of the kinematic variables provide some corroborative evidence to support reinvestment theory. Specifically, they suggest that variations in conscious processing might exert effects on motor performance through subtle differences in movement kinematics (cf. Maxwell et al., 2003).

Limitations and Future Directions

These results should be interpreted in light of some potential methodological limitations. First, the order that participants completed the conditions (i.e., low, medium, high-pressure) was fixed rather than counter-balanced. A fixed order was adopted in line with previous studies (e.g., Beilock & Carr, 2001) to prevent reduced motivation during low pressure that can occur when high pressure precedes low pressure. However, it is possible that improved performance during high pressure could have occurred due to learning rather than being an effect of competitive pressure per se. It is argued that the current results were not driven by learning because participants were highly trained experts, and accordingly, at their autonomous stage of motor skill learning, performance is expected to be stable (Fitts & Posner, 1967).

Second, indices of positive emotion were not assessed. Markers of increased intrinsic motivation, for example enjoyment, have been identified as factors that contribute to improved performance with increased competitive pressure (Tauer & Harackiewicz, 2004). Future studies could examine the positive emotions associated with competitive pressure, and utilise both self-report and objective psychophysiological measures (Blascovich et al., 2004).

Finally, attentional capacity and allocation of resources were not assessed. This was to help maximise the ecological validity of the pressure manipulations. However, in employing dual-task paradigms or attentional probing tasks, future research could more directly examine the predictions of cognitive theories of performance in sport (see Beilock, Carr, MacMahon, & Starkes, 2002; Murray & Janelle, 2003).

Conclusion

These data add further evidence to demonstrate that competitive pressure elicits effects on psychological, physiological and kinematic variables, and they offer some support for processing efficiency theory as an explanation for increased putting accuracy with increased pressure. In addition, they generate some support for the principles that underpin reinvestment theory, as more putts tended to be holed when the level of conscious processing was lowest, and more expert-like movement kinematics (i.e. less jerky swing) were observed. It remains for future research to pursue this exciting multi-disciplinary approach and draw a more detailed illustration of the pressure and performance relationship.

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CHAPTER FOUR

Effects of Competition on Endurance Performance and the Underlying Psychological and Physiological Mechanisms

Abstract

Competition can influence performance, however, the underlying psychological and physiological mechanisms are poorly understood. To address this issue this experiment tested mechanisms underlying the competition–performance relationship. Measures of anxiety, effort, enjoyment, autonomic activity and muscle activity were obtained from 96 participants during a handgrip endurance task completed in individual and competition conditions. Competition improved endurance performance, increased anxiety, effort, enjoyment, heart rate and muscle activity, and decreased heart rate variability, R-wave to pulse interval and pulse amplitude. Enjoyment fully mediated whereas effort and heart rate variability partially mediated the effects of competition on performance. In addition, anxiety moderated the competition–performance relationship; those with lower anxiety performed better in competition. Results confirm that competition elicits effects on performance through psychological and physiological pathways, and identify mechanisms that underlie improved endurance performance during competition.

Introduction

Competition is a common feature in multiple domains of society, such as education, business and sport. It is well established that competition influences our performance of tasks ranging from motor skills (e.g., Stanne, Johnson, Johnson, 1999) to academic tests (e.g., Belfield & Levin, 2002). However, the precise mechanisms that underlie competition-induced changes in performance remain a source of debate (Beilock & Gray, 2007). This is particularly true of endurance performance, with the majority of previous competition studies focusing on the performance of motor skills (e.g., Tauer & Harackiewicz, 2004) or laboratory-based tasks that impose minimal physical demands (e.g., Harrison et al., 2001). Tasks that require muscular endurance are prominent in a range of domains (e.g., construction work in industry; marathon running in sport) and are often performed in competition. With the aim of improving our understanding of the competition–performance relationship, this study investigates some of the psychological and physiological processes that could mediate and moderate the effects of competition on muscular endurance performance.

Psychological Effects of Competition

Competitions are associated with social comparison and evaluation, and often include rewards for success (Martens, 1975). As such, competitions serve as incentives for optimal or superior performance, and are considered sources of pressure (Baumeister & Showers, 1986). Anxiety, which is an aversive emotional state that is characterised by feelings of worry (Eysenck, Derakshan, Ramos & Calvo, 2007), is often experienced during high-pressure competitions (Martens, 1975). Accordingly, processing efficiency theory (Eysenck & Calvo, 1992), which offers an anxiety-based explanation of performance variability, could provide one account of the effects of competition on performance. Alternatively, competition has also been associated with increased enjoyment – a positive-valenced emotion that is characterised by feelings of pleasure. Tauer and Harackiewicz (2004) offer an enjoyment-based model that may also help explain the effects of competition on performance. In this experiment, both of these accounts of the competition–performance relationship were examined.

Processing Efficiency Theory

Processing efficiency theory is seated within Baddeley's tripartite model of the working memory system (Baddeley, 1986). This system consists of three components arranged in a hierarchical fashion. At the top is the central executive, which is a limited capacity control centre responsible for active processing and self regulatory functions, such as performance monitoring and strategy selection (Eysenck, et al., 2007). There are also two slave systems, namely, the phonological loop, which is responsible for rehearsal and storage of verbal information, and the visuospatial sketchpad, which is responsible for the storage of visual and spatial information (Derakshan & Eysenck, 2009). According to processing efficiency theory, the main effects of anxiety are on the central executive component of the working memory system. Specifically, anxiety is proposed to have two effects on the central executive. First, it consumes processing capacity through worry. When processing capacity is consumed to the extent that no auxiliary resources remain to retain on-task attention, performance is impaired. Second, it increases effort, defined in terms of the amount of resources allocated to the task (Eysenck & Calvo, 1992). Increased effort can enhance performance by mobilizing auxiliary processing resources that increase the amount of attention devoted to a task. A key distinction is made between performance effectiveness (i.e., the quality of performance) and efficiency (i.e., effectiveness in relation to the amount of effort expended). As performance effectiveness can be maintained by compensatory increases in effort, anxiety is proposed to impair efficiency more than effectiveness.

Several studies offer support for processing efficiency theory as an explanation for improvements (e.g. Eysenck, 1985) and impairments (e.g., Wilson, Smith, Chattington, Ford & Marple-Horvat, 2006) in both cognitive and motor performance during competition (for reviews see Eysenck & Calvo, 1992; Wilson, 2008). However, the predictions of the theory have not been tested in the context of an endurance task.

An Enjoyment Model

As well as the negative emotional state (e.g., high anxiety) that competition can invoke, it can also promote positively-valenced feelings (e.g., excitement, challenge) (Epstein & Harackiewicz, 1992). Based on positive emotion, Tauer and Harackiewicz (2004) offered an alternative explanation to that outlined by processing efficiency theory for competition-induced improvements in performance. Specifically, in a series of studies they demonstrated that team competitions reliably increased enjoyment and basketball shooting performance. Next, they applied mediation analyses to statistically examine enjoyment as an underlying mechanism of the observed facilitative effect of competition on motor performance. They found increased enjoyment was partially responsible for improved performance during competition. The suggestion that positive emotions, such as enjoyment, should be implicated in good performance is supported by a wealth of research that associates positive emotions with positive outcomes (for review see Lyubomirsky, King, & Diener, 2005). However, this enjoyment-based mechanism requires replication across different tasks to confirm its generalisability and robustness.

Physiological Effects of Competition

In addition to the psychological effects of competition, it is well documented that competitive pressure also elicits effects on autonomic nervous system activity (e.g., Harrison et al., 2001). Accordingly, it is possible that variations in autonomic activity could also help to further explain the effects of competition on endurance performance. To examine the effects of competition on autonomic activation, Veldhuizjen van Zanten et al. (2002) measured cardiovascular activity at rest, and while participants completed a series of competitive remote control car racing tasks. They found that competition elicited a pattern of cardiovascular activity indicative of increased beta-adrenergic activation of the heart (shortening of the cardiac pre-ejection period, and, to a lesser extent, increased heart rate), and increased alpha-adrenergic activation of the vasculature (increased total peripheral resistance). Competition also decreased heart rate variability, indicative of a decrease in parasympathetic cardiac control (Stein & Kleiger, 1999). However, the influence of these patterns of autonomic activity on measures of performance has yet to be assessed. In particular, it would be interesting to evaluate the influence of heart rate and heart rate variability on performance. This is because these measures have been suggested as indicative of emotions (e.g., increased heart rate could indicate increased anxiety or joy) and effort (e.g., decreased heart rate variability has been proposed to indicate increased effort) (for review see Kreibig, 2010; Mulder, 1992). Importantly, anxiety, joy and effort are key variables in the two alternative accounts of the competition–performance relationship that are outlined above.

In addition to its effects on the autonomic nervous system, competitive pressure also elicits effects on muscular activity. The effects of neuromuscular responses to competition on performance were recently examined by Cooke et al. (in press). During the motor skill of putting a golf ball, they observed increased muscle activity in the forearm during conditions of increased competitive pressure. This increase, which was suggested to indicate an inefficient tensing of the muscle, was partially responsible for impaired performance during competitive conditions. This finding demonstrates that physiological variables can play a role in explaining the competition–performance relationship.

Importantly, the effects of competition on muscle activity were also examined in one of the few competition studies to consider endurance performance (i.e., Voor, Lloyd, & Cole, 1969). They measured electromyographic activity of the bicep brachii while two groups of participants maintained 50% of their maximum voluntary contraction on an isometric dynamometer. One group of participants completed the endurance task individually, in a "do your best" goal-structured condition. A second group completed the task in teams of three (consecutively within each team), as part of a competition where the team with the greatest mean endurance time won a cash prize. No differences in endurance times were noted. However, greater muscular activation was recorded by those performing under competitive pressure than those performing alone. It was suggested that the pressure of competition may increase arousal, compromise muscular efficiency, and accelerate the rate of neuromuscular fatigue. However, as endurance times of the two groups did not reliably differ, this suggestion could not be confirmed. Similar findings were reported in a follow up study by Lloyd and Voor (1973). Taken together, these studies of the effects of competition on endurance performance provide evidence that competitive pressure is associated with less efficient patterns of muscular activation. Thus, reductions in muscular efficiency could provide a mechanism through which competition could exert detrimental effects on endurance performance.

The Present Study

The literature reviewed above suggests that competition can exert effects on performance through a variety of pathways. However, although research has documented that competition can affect performance and produce changes in psychological and physiological variables, only two studies (Cooke et al., in press; Tauer & Harackiewicz, 2004) have applied mediation analyses to examine causal mechanisms. Second, although several studies have assessed psychological and physiological effects of competition in isolation, few studies (e.g., Cooke et al., in press) have assessed them simultaneously. A multi-disciplinary approach has been recommended to provide fuller insights into the mechanisms that underlie performance under competitive pressure (Beilock & Gray, 2007). Third, previous competition studies have examined the effects of competition on academic and motor skill performance, but few (e.g., Voor et al., 1969) have examined endurance performance. Moreover, none have tested putative underlying mechanisms of the competition–endurance performance relationship. Such an approach is needed to examine the generalisability of potential mediators of performance (e.g., enjoyment, muscle activity) across multiple tasks.

In light of these limitations, the present study concurrently examined psychological and physiological responses as well as endurance performance during competition. As an extension of the study by Voor et al. (1969), psychological and autonomic reactions were assessed in addition to muscle activity, to afford a more comprehensive test of the potential psychological and physiological accounts of the competition–performance relationship outlined above. This is the first experiment, to the author's knowledge, to adopt such a multi-disciplinary approach to investigate the effects of competitive pressure on endurance performance. It was hypothesized that the competition manipulation would elicit increases in anxiety, effort (Eysenck & Calvo, 1992) and enjoyment (Tauer & Harackiewicz, 2004). Second, competition was expected to produce increased beta-adrenergic activation of the heart and alpha-adrenergic activation of the vasculature as well as decreased heart rate variability (Veldhuizjen van Zanten et al., 2002), and an inefficient increase in muscle activity (Voor et al., 1969).

The primary purpose was to examine whether increased competitive pressure is associated with changes in endurance performance and to formally evaluate mechanisms underlying the competition–performance relationship using mediation and moderation analyses. Based on the literature described above, effort and/or enjoyment, and/or cardiovascular activity were expected to mediate improved performance during competition. In contrast, anxiety and/or cardiovascular changes and/or inefficient muscle activity were expected to mediate performance during competition if endurance was impaired. Finally, based on processing efficiency theory, it was expected that anxiety would moderate the competition–performance relationship, with participants who experienced less anxiety being more likely to improve performance during competition.

Methods

Participants

Ninety-six (48 men, 48 women) healthy undergraduate students with a mean age of 19.7 (*SD* = 1.1) years, mean height of 1.73 (*SD* = 0.09) m, and mean mass of 67.5 (*SD* = 12.2) kg participated in the experiment. Individuals were excluded if they had any recent arm injury or current illness. Participants were asked to refrain from consuming alcohol in the 12 hours prior to testing, refrain from vigorous exercise for four hours prior to testing, and refrain from ingesting caffeine in the three hours and smoking in the two hours preceding participation (cf. Perkins et al., 1994; Perkins et al., 1995). Informed consent was obtained from all participants. The study was approved by the local research ethics committee. Physiological data from one participant were unscorable and one outlier was identified due to an irregular heartbeat; these participants were removed from the database. Thus, the effective sample size for the analyses reported comprised 48 male and 46 female participants.

Task and Design

Participants were required to squeeze a bespoke handgrip dynamometer (see Radwin, Masters, & Lupton, 1991) continuously, maintaining a grip force equivalent to at least 40% of their Maximum Voluntary Contraction (MVC) for as long as possible. This endurance task was chosen for several reasons. First, the task demands were simple to comprehend and, therefore, to comply with. Second, it generated an accurate measure of performance, in terms of endurance time that was measured to the nearest millisecond (see description of performance measure detailed later). Third, it permitted a relative force requirement (40% MVC) to be set, thus, taking account of individual differences in absolute strength. Finally, the 40% MVC force requirement was selected, based on previous literature (West, Hicks, Clements & Dowling, 1995) and pilot testing, to create a task that was expected to last sufficiently long for psychological processes to influence performance (cf. Voor et al., 1969).

Participants sat upright and used their dominant hand to hold the dynamometer, which was supported so that their arm was flexed at approximately 100°. A single 40 mm wide by 55 mm high dual-color (green, red) 7-segment light emitting diode panel positioned opposite each participant displayed grip force information. Green numbers were displayed to indicate a force equal to or greater than 40% MVC. For example green 0 represented a grip-force equivalent to 40% MVC, green 1 represented a grip-force equivalent to 41% MVC, and so on. Red numbers indicated a grip-force below 40% MVC (red 1 = 39% MVC, red 2 = 38% MVC, etc). Participants were asked to maintain a grip force that ensured the light emitting diode feedback display showed a low green number (i.e., to help ensure that the actual force maintained was close to the 40% MVC threshold) for as long as possible. The task terminated when grip force fell below 40% MVC for more than two seconds.

The experiment employed a within-subject design. Accordingly, participants completed the endurance task in both individual and competition conditions (described below), with the order counterbalanced.

Procedure

Participants attended a 75-minute testing session in single-sex groups of six individuals. First, informed consent was obtained, and demographics plus height and weight were recorded. Each participant was then assigned to an experimenter at one of six partitioned stations, arranged in an oval shape, in the laboratory. Instrumentation and instruction took place next. To improve the fidelity of physiological signals (see Measures section below), recording sites were exfoliated (Nuprep, Weaver) and degreased with alcohol wipes (Sterets, Medlock) prior to electrodes being affixed. Furthermore, the same experimenters were used throughout.

Following instrumentation and instruction, each participant's MVC was recorded. Specifically, participants used a handgrip dynamometer to perform three maximal contractions, separated by three minutes of rest to allow for recovery (Voor et al., 1969). Peak forces were recorded and MVC was classified as the largest (M = 472.5, SD = 121.2 N) of the three contractions (Voor et al., 1969). Next, 40% MVC was calculated and entered into a bespoke computer program to set the force that each participant had to maintain in the endurance task. It is worth noting that the following steps helped ensure that the MVC was accurate: (a) the experimenter monitored the force output on the computer screen to ensure that the profile was characteristic of a maximal effort, and (b) participants were not aware that their MVC informed the force requirement in the subsequent endurance task.

After MVC had been obtained and entered, participants sat quietly and rested during a 5-minute formal rest period to allow resting baseline physiological data to be acquired (see Data Reduction section). Following the rest, the endurance task was explained (see Task section). Participants then completed the endurance task in the first condition (i.e., individual or competition), with the order counterbalanced across participants. This was followed by a 5-minute recovery period during which participants completed the self-report measures to assess how they felt *during* the previous task. Physiological data were recorded continuously during each condition. Data were acquired through a Power1401 (CED) by a computer running Spike2 software. All signals were digitised at 2500 Hz with 16-bit resolution. This sequence (i.e., rest, instruction, task, recovery) was then repeated in the second counterbalanced condition. At the end of the session, participants were thanked, debriefed, and asked not to disclose information of the experiment with others. The two conditions were as follows:

Individual 'do your best' condition

In the individual condition, participants completed the task individually at their partitioned station, in the presence of only their own experimenter.

Competition condition

In the competition condition, all six participants present in the testing session completed the task simultaneously, in the presence of all six experimenters. In this condition, participants were also informed that a prize of £15 would be awarded to the individual who maintained the contraction for the greatest duration. They were further informed that, as a group of six, they would compete as a team against groups from the other testing sessions. Finally, they were told that a further £30 would be awarded to the team with the greatest average endurance time. This was to match real-life competition which often offers rewards (e.g., a prestigious trophy in sport, a college place in education, or a sales bonus in business). It is also in line with previous studies of competition that utilised evaluation and rewards within their competition manipulation (e.g., Cooke et al., in press; Harrison et al., 2001; Voor et al., 1969). As a final feature of the competition manipulation, the partitions that divided the stations were wheeled away, ensuring that each participant was in full view of the other participants. This was to maximise the social evaluation and comparison that is associated with competition (Martens, 1975), again making the laboratory environment more akin to the sort of competition that is prevalent in the real world.

Performance Measure: Endurance time

In line with previous research (e.g., Bray, Ginis, Hicks, & Woodgate, 2008), the amount of time that the isometric contraction was maintained in each condition was used to measure endurance performance. To provide a standardised measure of the point at which the isometric contraction failed, the grip force maintained by participants was also recorded. Specifically, endurance time was measured as the time between task onset and the point when grip force fell below 40% MVC for more than two seconds. Force data were recorded through an analogue-to-digital convertor (Power 1401, CED) and digitised at 2500 Hz with 16-bit resolution. Force and endurance time were recorded by a computer running Spike2 software.

Psychological Measures

Competitive pressure manipulation check. To check the effectiveness of the competition manipulation in creating competitive pressure, participants completed the 5-item pressure/tension subscale from the Intrinsic Motivation Inventory (Ryan, 1982). Participants were asked to rate items, including “I felt pressured” and “I felt very tense” on a 7-point Likert scale (*1= not at all true, 4= somewhat true, 7= very true*). The item responses were averaged to provide one score for the scale. McAuley, Duncan, and Tammen (1989) reported an internal consistency of .68 for this subscale. In this experiment, the Cronbach’s alpha coefficient in the individual condition was low (.58). Removal of the negatively scored item “I did not feel nervous” improved the internal consistency across conditions to an acceptable level in both the individual (.77) and competition (.82) conditions. Thus, the pressure scores were computed without this item.

Anxiety. The cognitive anxiety item from the Mental Readiness Form-Likert (MRF-L, Krane, 1994) was used to measure anxiety. Participants were asked to rate their thoughts on an 11-point scale anchored with the terms *calm* and *worried.* Although the use of one-item scales has sometimes been criticized, this brief measure was chosen so that participants could give a quick and simple assessment of anxiety, in mind of the time required to complete the other self-report measures. Krane (1994) has reported correlations between the MRF-L and the Competitive State Anxiety Inventory-2 of .76 for cognitive anxiety, supporting the concurrent validity of this measure. Previous studies have used this instrument to assess anxiety in competitive settings (e.g., Robazza, Bortoli, & Nougier, 2000).

Effort. A version of Zijlstra’s (1993) rating scale for mental effort was used to assess effort. Specifically, participants were instructed to rate the level of effort that they expended (cf. Mullen, Hardy & Tattersall, 2005) using a vertical axis scale ranging from 0–150, with increments of 10 shown on the left edge of the scale and nine category anchors shown on the right edge of the scale. These included *no effort at all* (at 3 on the scale), *a fair amount of effort* (at 58 on the scale), and *extreme effort* (at 114 on the scale). The original scale has acceptable test-retest reliability, with a correlation coefficient of .78 (Zijlstra, 1993), and has been used previously to assess effort during competition (e.g., Wilson et al., 2006).

Enjoyment. Enjoyment was assessed by the 7-item enjoyment subscale of the Intrinsic Motivation Inventory (Ryan, 1982). Items, including "It was fun to do", were rated on a 7-point Likert scale, with anchors of 1 (*not at all true*), 4 (*somewhat true*), and 7 (*very true*). The item responses were averaged to provide one score for the scale. McAuley et al. (1989) have reported an internal consistency of .78 for this subscale. In this experiment, Cronbach's alpha coefficients across the two conditions were very good (.82 to .84).

Physiological Measures

Autonomic activity. An electrocardiogram was obtained using three silver/silver chloride spot electrodes (Cleartrace, ConMed) in a modified chest configuration. Active electrodes were positioned on the right clavicle and a lower left rib with a reference electrode positioned on the left clavicle. The electrocardiographic signal was amplified and filtered (0.1–300 Hz plus 50 Hz notch filter) by an AC amplifier (LP511, Grass). Heart rate and heart rate variability during each condition were derived from the intervals between R-waves of the electrocardiogram. The square root of the mean of the sum of squared successive difference in cardiac interbeat intervals (r-MSSD) and the standard deviation of R-wave to R-wave intervals (SDNN) were computed as measures of heart rate variability. r-MSSD is a time domain surrogate of the frequency domain based high (0.15–0.40 Hz) spectral power band (Stein & Kleiger, 1999), which reflects parasympathetic nervous system activity. SDNN is a time domain index of heart rate variability that closely reflects activity in the frequency domain-based low (0.04– 0.15 Hz) spectral power band (Carrasco, Gaitan, Gonzalez, & Yanez, 2001), and is influenced by both sympathetic and parasympathetic inputs.

In addition, an infrared photoplethysmograph (1020 EC, UFI) was used to measure pulse at the right ear. The pulse signal was amplified by a custom made amplifier with a gain of 100 and a bandwidth of 0.06 to 35 Hz. The R-wave to ear pulse interval was calculated to indicate beta-adrenergic activation of the heart (De Boer, Ring, Curlett, Ridley, & Carroll, 2007). This was calculated as the time between the peak of the R-wave of the electrocardiogram and the foot of the systolic upstroke of the ear pulse. The foot was defined as the point when the slope of the pulse upstroke was 25% of the maximum slope of that upstroke (Lane, Greenstadt, Shapiro, & Rubinstein, 1983). A decrease in R-wave to pulse interval indicates increased beta-adrenergic activation (Montoya, Brody, Beck, Veit & Rau, 2002). The amplitude of the blood pressure pulse wave was also recorded to indicate alpha-adrenergic activation of the vasculature (Iani, Gopher & Lavie, 2004). Pulse amplitude was computed as the difference between the foot and peak of the pulse waveform. A decrease in pulse amplitude indicates increased vasoconstriction and alpha-adrenergic activation of the vasculature (Iani et al., 2004).

Muscle activity. Electromyographic activity of the preferred arm was recorded from the extensor carpi radialis and flexor carpi ulnaris forearm muscles that are used for gripping. Differential surface electrodes mounted together with a reference electrode in a 30 by 20 by 10 mm case containing a ×1000 pre-amplifier were used to record electromyographic activity. Two 5 mm diameter active electrodes, separated by 15 mm, were oriented longitudinally along the muscle with the 5 mm diameter reference electrode positioned between the two active electrodes offset 10 mm laterally (Johnson, Lynn, Miller, & Reed, 1977). Electrodes were placed on the belly of each muscle group, approximately 10 cm from the medial epicondyle of the humerus in the case of the flexor, and 8 cm distal to the lateral epicondyle of the humerus in the case of the extensor. Conductive cream was applied to the electrode contacts. The electromyographic signal was amplified (×2) and filtered (10 – 1000 Hz) by a custom made amplifier prior to digitization at 2500 Hz with 16-bit resolution (Power 1401, CED).

Data Reduction

To standardize responses across participants, and in line with previous research (e.g., Bray et al., 2008), force and electromyographic activity were expressed relative to the values recorded during the MVC. Values were calculated to represent mean physiological activity at baseline and in the two experimental conditions (i.e., individual, competition). Baseline activity was calculated during the final (i.e., fifth) minute of the rest period that preceded the first condition. Baseline activity was assessed to illustrate the physiological impact of the tasks (Harrison et al., 2001; Veldhuijzen van Zanten et al., 2002).

Moreover, to give insight into any changes in force and physiological activity within each condition, force and physiological activity were also calculated during each quartile (i.e., 0–25%, 26–50%, 51–75% and 76–100% of total endurance time) of the contraction in the individual and competition conditions. For the purposes of testing mediation and moderation, the primary interest was in any overall condition differences in physiological activity. However, assessing within-condition changes, as has been done by previous studies (e.g., Bray et al., 2008; Voor et al., 1969), allowed an observation the time course effects of physiological changes. Based on previous research (e.g., Bray et al., 2008; Voor et al., 1969), it was expected that linear trends would emerge, indicating increases in sympathetic activation and muscle activity as the tasks progressed.

Statistical Analysis

Exploratory analysis of the data, which included sex as a between-subject factor, revealed no sex main effect and no sex by condition interaction effect for any variable, with the exception of relative muscle activity, which tended to be greater for females. Importantly, sex did not influence endurance performance, and, therefore, the analyses reported below do not include sex as a factor.

Performance and psychological data. A 2 condition (individual, competition) repeated measures MANOVA to examine the effects of condition on the performance and psychological variables was conducted first. Significant multivariate effects were followed by separate repeated measures ANOVAs for each variable. Significant ANOVA effects were followed by planned contrasts where appropriate. Partial eta-squared (η_p^2) is reported as a measure of effect size. In ANOVA this equals the adjusted R^2 obtained in regression analyses (Tabachnick & Fidell, 2001). Values of .02, .13 and .26 for η_p^2 indicate small, medium and large effect sizes, respectively (Cohen, 1992).

Physiological data. Physiological activity was firstly examined within each condition, to explore the physiological demands of the endurance task. A 2 Condition (individual, competition) × 4 Phase (0–25%, 26–50%, 51–75%, 76–100% of total endurance time) repeated measures MANOVA was used to assess changes in the physiological variables as a function quartile of the task and condition. As the physiological signals were expected to change in a linear fashion during the task, significant MANOVA effects were followed by planned polynomial trend analyses (Keppel, 1982).

The values that represented the mean score for each variable at baseline and in each experimental condition were also compared. A 3 condition (baseline, individual, competition) repeated measures MANOVA was conducted to examine the physiological impact of the tasks. This was followed by separate repeated measures ANOVAs and planned contrasts, as described previously.

Mediation and moderation. Finally, regression analyses were used to examine mediation and moderation. Due to the within-subjects design, these analyses were conducted in line with the difference/sum regression procedure outlined by Judd, Kenny, and McClelland (2001). This procedure and the results of these analyses are presented in the results section.

Results

Performance and Psychological Measures

A repeated measures MANOVA examined the effect of condition (individual, competition), a within-subject factor, on the performance and psychological variables. This analysis revealed a multivariate effect for condition, $F(6, 88) = 30.78$, $p < .001$, $\eta_p^2 = .68$. Subsequent ANOVAs (2 Condition) confirmed a main effect of condition on competitive pressure, $F(1, 93) = 122.82$, $p < .001$, $\eta_p^2 = .57$. As expected, competitive pressure was greater during the competition condition ($M = 4.10$, $SD = 1.16$) than the individual condition ($M = 2.86$, $SD = 1.17$), confirming the effectiveness of the competition manipulation.

ANOVA also detected a significant effect of condition on endurance performance, $F(1, 93) = 22.44$, $p < .001$, $\eta_p^2 = .19$. Participants maintained the isometric contraction for longer in the competition condition ($M = 119.14$, $SD = 39.84$ seconds) than in the individual condition ($M = 98.01$, $SD = 29.62$ seconds). ANOVA found no main effect of condition for force maintained, $F(1, 93) = 0.24$, $p = .63$, $\eta_p^2 = .00$. Participants maintained a grip force that was very close to the 40% MVC minimum requirement in both individual ($M = 42.42$, $SD =$

1.92 % MVC) and competition (*M* = 42.50, *SD* = 1.76 % MVC) conditions. Finally, ANOVAs confirmed that ratings of anxiety, effort and enjoyment were greatest in the competition condition (see Table 4.1).

Table 4.1: *Comparisons of the Psychological Measures in the Individual and Competition Conditions*

Measure (range of possible scores)	Condition					
	Individual		Competition			
	M	*SD*	*M*	*SD*	*F*(1, 93)	η_p^2
Anxiety (1-11)	4.06	1.81	5.88	2.05	104.12***	.53
Effort (0-150)	92.28	14.63	99.38	14.59	17.35***	.16
Enjoyment (1-7)	4.44	0.93	4.83	1.00	27.80***	.23

Note: ****p* <.001

Physiological Measures

A repeated measures MANOVA was used to examine changes in physiological activity as a function of condition and phase of the contraction. This analysis confirmed multivariate effects of phase, $F(24, 70) = 47.27$, $p < .001$, $\eta_p^2 = .94$, and condition by phase, $F(24, 70) = 4.85$, $p < .001$, $\eta_p^2 = .62$. Polynomial trend analyses confirmed linear increases in heart rate, pulse amplitude, and electromyographic activity, as well as linear decreases in heart rate variability and the R-wave to pulse interval, as the task progressed. In addition, condition by phase interactions in the linear component were noted for heart rate and muscle activity, which increased more during competition. Moreover, force decreased in a quadratic fashion, falling in the final quarter of the task. Figure 4.1 depicts these trends.

Next, a 3 condition (baseline, individual, competition) repeated measures MANOVA was conducted to examine the overall effects of condition on the physiological variables. This analysis considered only the overall mean value for each physiological variable that was recorded during each condition. It revealed a multivariate effect for condition, $F(14, 80) = 200.97$, $p <.001$, $\eta_p^2 = .97$. Separate 3 Condition (baseline, individual, competition) ANOVAs then compared the effects of condition on the physiological variables individually. As expected, all measures changed from baseline to the experimental conditions (see Table 4.2). Moreover, all measures differed between the individual and competition conditions, with the exception of flexor carpi ulnaris muscle activity (Table 4.2).

Mediators and Moderators of Performance

To examine mediation and moderation the difference/sum regression procedure was followed. This procedure was outlined by Judd et al. (2001) for use with repeated measures designs. To conduct these analyses, there must be condition differences in the dependent variable (endurance time) and potential mediator/moderator variables (i.e. the psychological and physiological variables). The results presented above satisfied these two conditions. On average, endurance time was 21.13 seconds longer in the competitive condition than in the individual condition, which represents a medium-to-large effect size. Moreover, all psychological and autonomic variables, plus extensor muscle activity, differed between the individual and competition conditions.

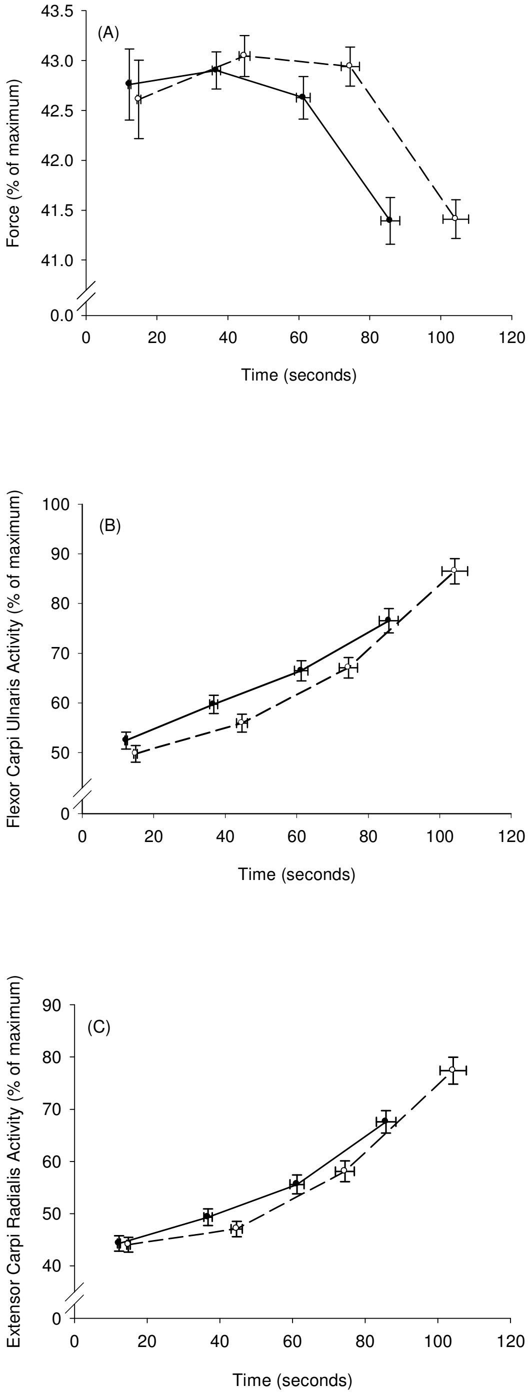

Figure 4.1. (A) Relative force maintained at each quartile of total endurance time. (B) Relative flexor carpi ulnaris activity at each quartile of total endurance time. (C) Relative extensor carpi radialis muscle activity at each quartile of total endurance time. Solid line represents individual condition. Dashed line represents competition condition. Horizontal error bars depict standard error (seconds) of the mid-point of each quartile; vertical error bars depict standard error of the given variable.

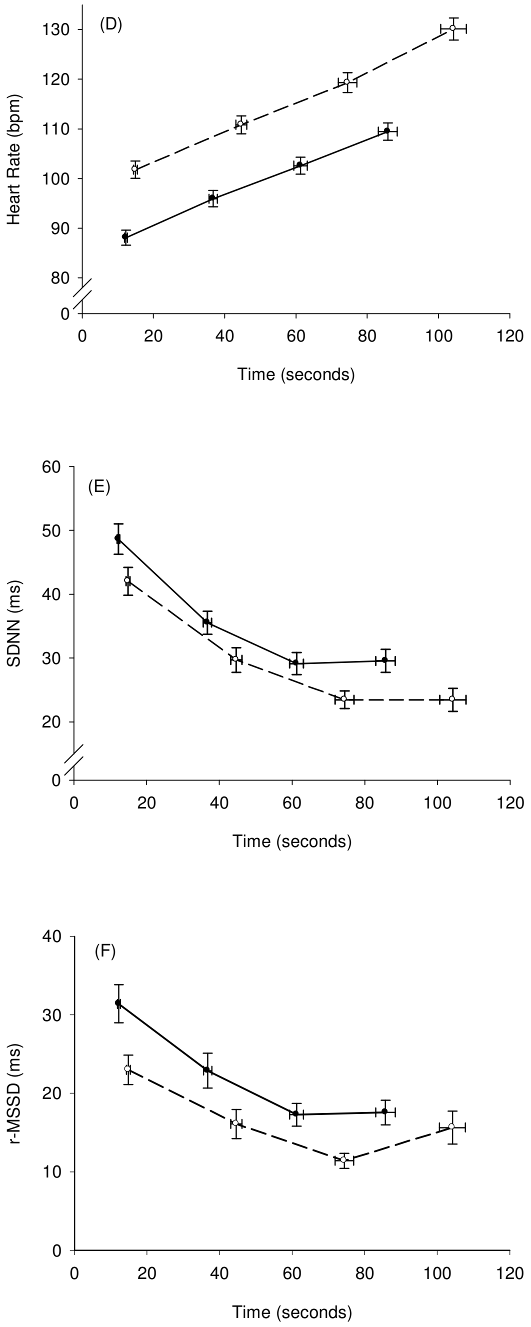

Figure 4.1. (D) Heart rate at each quartile of total endurance time. (E) SDNN at each quartile of total endurance time. (F) r-MSSD at each quartile of total endurance time. Solid line represents individual condition. Dashed line represents competition condition. Horizontal error bars depict standard error (seconds) of the mid-point of each quartile; vertical error bars depict standard error of the given variable.

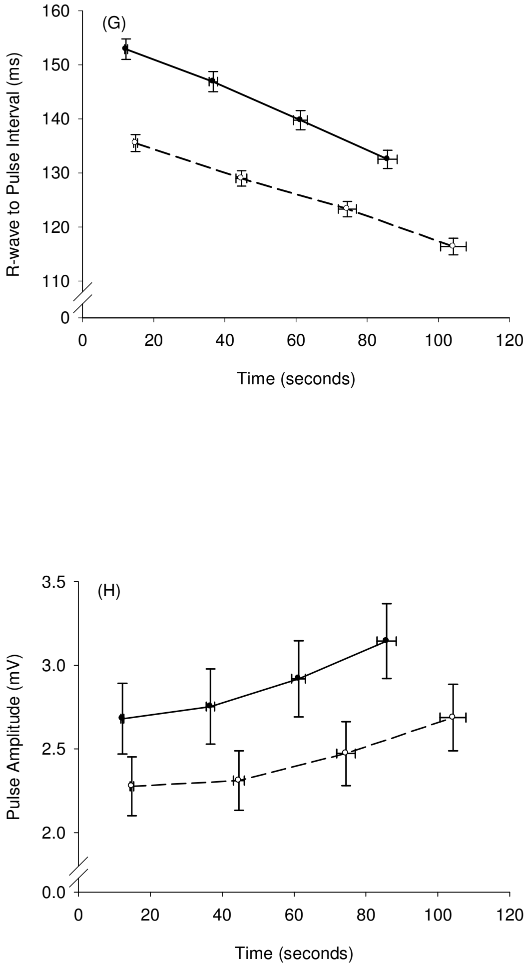

Figure 4.1. (G) R-wave to pulse interval at each quartile of total endurance time. (H) Pulse amplitude at each quartile of total endurance time. Dashed line represents competition condition. Horizontal error bars depict standard error (seconds) of the mid-point of each quartile; vertical error bars depict standard error of the given variable.

Table 4.2: *Comparisons of the Physiological Measures during Baseline and in the Individual and Competition Conditions*

Measure	Condition							
	Baseline		Individual		Competition			
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*(2, 92)	η_p^2
Heart rate (bpm)	74.51	11.73	99.00 ^{a}	15.23	115.50 ^{a,b}	17.63	357.82***	.89
SDNN (ms)	84.16	35.33	35.71 ^{a}	14.60	29.66 ^{a,b}	13.18	116.52***	.72
r-MSSD (ms)	66.36	42.21	22.27 ^{a}	14.33	16.52^{a,b}	11.56	68.57***	.60
R-wave to pulse interval (ms)	163.96	17.63	142.99 ^{a}	16.52	126.01^{a,b}	13.54	376.42***	.89
Pulse amplitude (mV)	2.64	1.89	2.87 ^{a}	2.11	2.44 ^{a,b}	1.74	11.45***	.20
Extensor carpi radialis muscle activity (% MVC)	4.91	3.91	54.19 ^{a}	15.31	56.66 ^{a,b}	16.17	579.62***	.93
Flexor carpi ulnaris muscle activity (% MVC)	4.62	3.41	63.81 ^{a}	17.67	64.84 ^{a}	17.50	657.72***	.94

Note: Letters a and b indicate significant difference from baseline and individual conditions respectively. ****p* <.001.

As performance was improved with competition, effort, enjoyment, and the cardiovascular variables were examined as mediators, and anxiety was examined as a moderator of the observed competition–performance relationship.

Accordingly, regression analyses were conducted to predict the difference in competition versus individual endurance time from (a) the difference in each potential mediator/moderator across conditions and (b) the mean centred sum of each potential mediator/moderator in the two conditions. If the condition difference in each potential mediator/moderator predicts the difference in endurance time then mediation can be inferred. If the mean centred sum predicts the difference in endurance time there is evidence for moderation (Judd et al., 2001). The residual difference, which represents any variance over and above mediation, is indicated by the unstandardised *b*, which is used in these analyses because standardised solutions are not scale invariant for multiple points.

Analyses revealed that the original 21.13 second difference in endurance time between conditions was significantly reduced to 14.29, 12.20, and 6.65 seconds respectively, when the condition differences in SDNN, effort, and enjoyment were considered in the regression equation. Although the original difference was significantly reduced, the residual differences of 14.29 and 12.20 seconds that remained in the presence of SDNN and effort still represented a significantly greater endurance time during competition. As these variables significantly reduced the variance in endurance time, but did not eliminate it, they can be considered partial mediators of the facilitative effect of competition on endurance performance. The residual difference of 6.65 seconds that remained in the presence of enjoyment no longer represented a significantly greater endurance time during competition. As a consequence, enjoyment can be considered a full mediator of the facilitative effects of competition on endurance performance. Having identified these mediators, each of them and their respective mean centred sum were considered in a single regression model. As expected, when SDNN, effort and enjoyment were entered simultaneously, the original 21.13 second variance in endurance time was fully accounted for, as the residual variance was reduced to -1.00 second.

The expected moderated effect was revealed for anxiety, $b = -2.93$, $t(91) = 2.28$, $p < .05$. This negative relationship between anxiety and endurance time indicates that participants reporting lower anxiety manifested greater increases in endurance time from individual to competitive conditions (Figure 4.2).

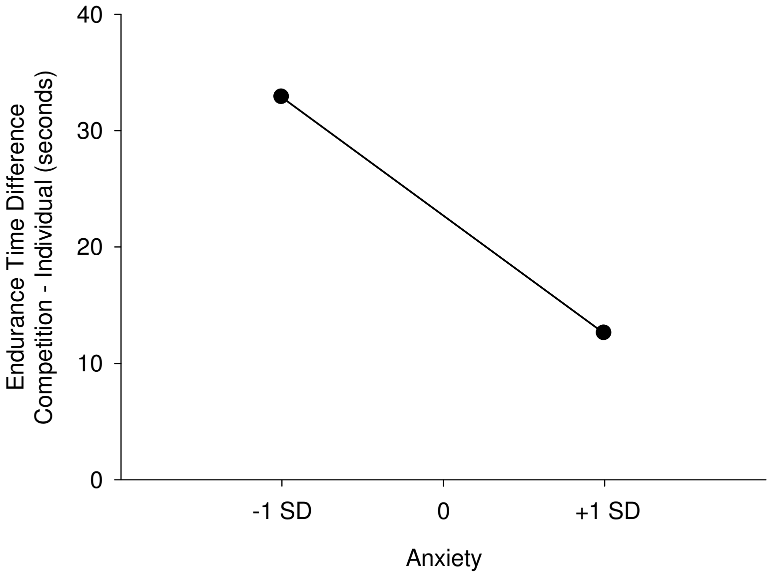

Figure 4.2. The moderating effect of anxiety on the difference in endurance performance between competition and individual conditions. Plot displays the slopes of the simple regression line (one *standard deviation* above and one *standard deviation* below the summed means).

Discussion

This study investigated the psychological and physiological processes that mediate and moderate performance during competition. Building on previous research, it is the first to formally test potential mediators and moderators of the relationship between competition and endurance performance. The manipulation check confirmed that ratings of pressure were greater during the competition condition than during the individual condition. Accordingly, the competition manipulation was successful in pressuring participants as per real-life competition (Baumeister & Showers, 1986).

Effects of Competition on Endurance Performance

Competitive pressure had a facilitative effect on endurance performance: Participants maintained the isometric contraction for an additional 21 seconds (i.e., 22% longer) in the competitive condition. The observation that competition facilitated performance compared to a ‘do your best’ structured condition is consistent with the majority of previous research (see Stanne et al., 1999 for review) into the effects of competition on motor skill performance. However, it is not consistent with some previous studies into the effects of competition on endurance performance (e.g., Voor et al., 1969). Methodological differences between this experiment and the experiment conducted by Voor et al. (1969) could be responsible for this discrepancy. For example, a larger sample was recruited and a within-subjects design was adopted in the present experiment. As a consequence, it is believed that this experiment was better powered to detect effects. In addition, the competition manipulation adopted in the present experiment involved teams of participants maintaining the isometric contraction concurrently, rather than consecutively. This could have maximised cooperation among participants within the competitive environment, which has previously been argued to improve performance during competition (Tauer & Harackiewicz, 2004).

Psychological Mediators and Moderators of Performance

Based on processing efficiency theory (Eysenck & Calvo, 1992), it was hypothesised that competitive pressure would increase anxiety and effort. These hypotheses were supported. Moreover, mediation analyses revealed that increased self-reported effort partially mediated the observed competition-induced improvement in endurance performance. This is one of the first studies to statistically confirm this hypothesized relationship (cf. Chapter 3). The data provide support for processing efficiency theory's account of improved performance under competitive pressure. Interestingly, anxiety was also implicated in the competition–performance relationship, as anxiety moderated performance: When anxiety is low, an individual is more likely to improve performance. This expected finding is also in line with processing efficiency theory. Specifically, the theory contends that less anxiety could be beneficial as it leaves more processing resources available, which could be focused on task performance through increased effort (Eysenck & Calvo, 1992). Taken with the findings regarding effort, these results provide the first direct evidence that effort mediated whereas anxiety moderated improved performance with competition. These novel findings add to the literature that has suggested such relationships for many years without formally testing them (cf. Eysenck & Calvo, 1992; Wilson, 2008).

As an alternative psychological explanation for improved performance during competition, it was hypothesised that competition would increase enjoyment, which could also explain improvements in performance (Tauer & Harackiewicz, 2004). These predictions were also supported. Enjoyment was greater during competition than during the individual condition, and, moreover, increased enjoyment fully mediated the facilitative effect of competition on endurance performance. As enjoyment accounted for a greater proportion of the variance in endurance performance (indicated by the smaller residual difference in endurance time that remained after mediation) than effort, it appears that this positive emotion / motivational account (see Tauer & Harackiewicz, 2004) of the competition–performance relationship is better than the negative emotion / cognitive account offered by processing efficiency theory (cf., Woodman et al., 2009). However, the elimination of unaccounted variance that was noted when both effort and enjoyment were considered in the same mediation model indicates that both accounts made a unique contribution to the explanation of competition induced changes in performance. It would be fruitful for future research to measure other positive and negative emotions (see Kreibig, 2010; Woodman et al., 2009) and further compare these accounts of the competition–performance relationship in different domains.

Physiological Mediators of Performance

Based on previous research (e.g., Veldhuizjen van Zanten et al., 2002), it was hypothesised that competition would elicit effects on the autonomic nervous system to reflect increased beta-adrenergic activation of the heart and alpha-adrenergic activation of the vasculature, as well as decreased heart rate variability. These hypotheses were supported. The overall pattern of effects for competition was indicative of increased beta-adrenergic activation of the heart (shortening of the R-wave to pulse interval, and to a lesser extent, increased heart rate), increased alpha-adrenergic activation of the vasculature (decreased pulse amplitude), and some vagal withdrawal (decreased heart rate variability) (Veldhuizjen van Zanten et al., 2002). These effects were evident in competition relative to the individual condition, and were also characteristics of within-condition changes that occurred as the isometric contraction was maintained in both conditions. It is possible, given the different endurance times recorded in each condition, that the overall differences in autonomic activity between the individual and competition conditions were an artefact of the longer contraction during competition. However, the within-condition analyses of the physiological measures would seem to counter this suggestion. They revealed that during the early phase of the contractions, both force and electromyographic activity in the two conditions were similar, yet there were already notable differences in the autonomic variables (see Figure 4.1). This suggests that the autonomic findings were not due to an increased metabolic demand in the competition condition.

Accordingly, mediation analyses were applied to examine the autonomic variables as mediators of the facilitative effect of competition on endurance performance. To the author's knowledge, this is the first experiment to statistically examine autonomic variables as mediators of the competition–endurance performance relationship. Results highlighted SDNN heart rate variability as a mediator of the facilitative effects of competition on performance. SDNN is a time-domain correlate of the frequency domain based low-spectral power band (0.04– 0.15 Hz) (Carrasco et al., 2001). Interestingly, decreased heart rate variability (0.07–0.14 Hz) has been argued to reflect increased effort (e.g., Mulder, 1992), which could provide an explanation for the mediating role that SDNN had in facilitating performance during competition. Specifically, if decreased SDNN reflects increased effort, then this finding would be supportive of processing efficiency theory, which argues that increased effort improves performance by allocating additional attention to a task (Eysenck & Calvo, 1992). However, SDNN did not correlate significantly with self-reported effort (*r*'s = .15 – .16, *p*'s = .13 – .14), and, therefore, this account must remain speculative and await further investigation. Such studies would do well to concurrently measure ventilation so that its effects on heart rate variability can also be taken into account (Mulder, 1992).

The final hypothesis of this experiment was that competition would elicit an inefficient increase in muscle activity (Cooke et al., in press; Voor et al., 1969). Muscle activity in the extensor carpi radialis, but not the flexor carpi ulnaris, was greater during competition. However, in the current study, the increase in extensor muscle activity that occurred during competition appeared not to be a result of inefficient activity due to increased arousal (cf. Cooke et al., in press; Voor et al., 1969). Instead, the overall increase in muscle activity during competition was driven in this experiment by an increase in electromyographic activity during the final stage of the contraction (Figure 4.1C). Eason (1960) also noted fairly stable increases in electromyographic amplitude during the initial phases of an isometric contraction, followed by exaggerated increases close to termination. He suggested that the extent of the increase in electromyographic amplitude during the final phase of an isometric contraction reflected the amount of additional conscious effort applied to maintain the contraction. As a more exaggerated increase close to the termination of the contraction during the competition condition was also noted here, this could reflect additional effort during the final stages of competition.

Study Limitations and Future Directions

The results of this experiment should be interpreted in light of some potential methodological limitations. First, competition was only compared with a non-competitive 'do your best' condition. Future studies should include different social climates of performance (e.g., cooperation, head-to-head competition) to more fully evaluate mediators and moderators of the effects of competitive pressure on performance. Second, features such as rewards and an evaluative audience were incorporated into the competition condition. As a consequence, it is possible that the beneficial effects on performance noted during competition could have resulted from these external pressures rather than from the process of competing per se. For instance, social facilitation researchers have demonstrated that an audience can improve performance of simple tasks (e.g., Zajonc, 1965), although this observation does not always hold (e.g., Strauss, 2002). It should be noted that this design was adopted because competition in the real world often incorporates such external pressures. Moreover, these features were incorporated in the competition manipulation that did not affect performance when used by Voor et al. (1969), and are typical in psychophysiological studies of competition (e.g., Cooke et al., in press; Harrison et al., 2001; Lloyd & Voor, 1973; Veldhuizjen van Zanten et al., 2002). Nevertheless, future studies could use simpler manipulations to re-examine any potential effects of audience and reward aside from the effects of competition on performance.

For example, Wright, Killebrew and Pimpalapure (2002) have demonstrated that effort and associated cardiovascular responses (broadly indicative of increased sympathetic activation) in "do your best" performance climates are influenced by the perceived value of success (see also Gendolla, Richter & Silvia, 2008). These findings are consistent with Brehm and Self's (1989) motivational intensity theory, which argues that effort is determined by a cost-benefit analysis of what an individual can do and is willing to do in order to succeed. Given the presence of social comparison and reward in the competition condition, it is likely that the perceived value of success was greater in the competition condition than the individual condition in this experiment. Accordingly, it is possible that these factors were responsible for the observed effects of competition on effort, cardiovascular reactivity, and performance. Future studies could investigate motivational intensity theory as an alternative to processing efficiency theory when investigating the role of effort and cardiovascular variables in the competition–performance relationship.

Similarly, Brehm's (1999) emotional intensity theory is also worthy of consideration here. One of the predictions of emotional intensity theory is that more intense emotional experiences lead to more resources being devoted to goal-based work. This provides a slightly different explanation (compared to the explanation outlined by processing efficiency theory) of how greater anxiety is often accompanied by increased effort. Indeed, it should be acknowledged that processing efficiency theory is limited because its view of the central executive component of working memory as being simply a limited capacity pool of processing resources is now somewhat outdated (see Baddeley, 2001). As such, processing efficiency theory fails to specify which of the newly identified central executive functions (e.g., inhibition, shifting, updating) are most affected by anxiety. Investigating alternatives accounts to processing efficiency could thus be a particularly fruitful avenue for future competition and performance research (see also Eysenck et al., 2007).

Conclusion

By concurrently examining psychological and physiological responses, the present study adds to the literature that demonstrates competition to elicit effects at both psychological and physiological levels of analysis (e.g., Cooke et al., in press). To advance previous literature, mediation and moderation analyses were applied to examine the underlying mechanisms of the competition–endurance performance relationship. It was found that competition improved endurance performance, an effect mediated by increased enjoyment and effort as well as decreased SDNN during the competition condition. Anxiety moderated performance, where less anxiety was associated with a greater improvement in endurance performance from individual to competition conditions. These results provide support for processing efficiency theory (Eysenck & Calvo, 1992) and positive emotional accounts (e.g., Tauer & Harackiewicz, 2004) of improved performance during competition.

These findings clearly demonstrate the powerful effects that competition can have on our thoughts, feelings and actions. It remains for future research to continue with this promising multi-measure approach to further develop our understanding of the mechanisms that underlie the effects of competition on performance.

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CHAPTER FIVE

All for One and One for All:
Enjoyment Facilitates Performance during Team Competitions

Abstract

Although it is well established that competition can influence performance, the mechanisms that underlie the competition–performance relationship are poorly understood. To address this issue this experiment examined emotions as mediators of the effects of competition on performance. Measures of enjoyment, anxiety, effort, cardiovascular activity and muscle activity were obtained from 64 participants during a handgrip endurance task completed in a series of individual and team competitions. Endurance performance was better, and enjoyment, anxiety, effort, and sympathetic activity were greater during team competitions. Physiological data confirmed the presence of negative emotions during competitions. However, mediation analyses revealed that enjoyment and effort (to a lesser extent) were the key variables responsible for mediating the effects of competition on performance. Results confirm that competition elicits effects on performance, and identify emotional mechanisms that facilitate performance during team competitions.

Introduction

Research examining the competition–performance relationship has been undertaken for over a century (e.g., Triplett, 1898). The potential for competition to elicit both positive and negative effects on performance is well established (e.g., Martens, 1975; Stanne, Johnson & Johnson, 1999), however, the mechanisms that underlie the competition–performance relationship remain a source of debate (cf. Beilock & Gray, 2007). Research has demonstrated that competition can elicit both positive (e.g., enjoyment) and negative (e.g., anxiety) emotional responses (e.g., Cooke, Kavussanu, McIntyre & Ring, in press; Tauer & Harackiewicz, 2004). As such, with the goal of improving our understanding of the social psychology of competition, this experiment is one of the first to examine emotions as mediators of the effects of competition on performance.

Competition and Positive Emotion

The effects of competition on positive emotion were examined by Tauer and Harackiewicz (2004). They demonstrated in a series of studies that team competitions reliably increased enjoyment and basketball shooting performance. Using statistical mediation analyses, they found that enjoyment was partially responsible for the observed facilitative effect of competition on motor performance. This represents one of only a handful of studies to statistically evaluate emotions as mediators of the effects of competition on performance (cf. Cooke et al., in press). Its finding is compatible with Fredrickson's (2004) broaden-and-build theory of positive emotion, which contends that positive emotions such as joy not only signal optimal performance, but also serve to produce it (Fredrickson, 2004).

Competition and Negative Emotion

The findings of Tauer and Harackiewicz (2004) do not sit well, in an intuitive sense, with the popular view that the effects of competition are associated with negative emotions, in particular, anxiety (e.g., Martens, 1975). Eysenck and Calvo's (1992) processing efficiency theory is a popular anxiety-based theory of performance. This contends that anxiety can impair performance by exceeding our limited attentional capacity with worrisome thoughts (e.g., Derakshan & Eysenck, 2009). However, it can also improve performance by motivating performers to invest additional effort and increase the amount of attention allocated to a task (Eysenck and Calvo, 1992). Despite the plethora of experiments which examine processing efficiency theory (see Eysenck & Calvo, 1992; Wilson, 2008), there is only limited evidence for the hypothesised mediating roles of anxiety and effort in impairing and improving performance, respectively (i.e., Chapter 3; Chapter 4).

Physiological Reactions to Competition

While few studies have statistically evaluated emotions as mediators of the competition–performance relationship, previous studies have also, for the most part, failed to assess objective physiological indices of emotion. The use of physiological measures is advantageous as they are covert and online, and thus, they can provide robust and interdisciplinary tests of theoretical predictions (Blascovich, 2006).

The recently proposed theory of challenge and threat states in athletes (Jones, Meijen, McCarthy & Sheffield, 2009) outlines how physiological reactions to competition could indicate positive and negative emotions. Specifically, the theory describes physiological reactions to competition that can distinguish between challenge and threat appraisals. Challenge appraisals are generally associated with positive emotions, and are characterised by increased sympathetic activation and decreased vascular resistance. Threat appraisals are generally associated with negative emotions, and are characterised by smaller increases in sympathetic activation, and unchanged or increased vascular resistance (Jones et al., 2009). Increased sympathetic activation can be characterised by an increased heart rate coupled with a decrease in the interval between the R-wave of the electrocardiogram and the peripheral pulse (Contrada, Del Bo, Levy & Weiss, 1995). Variations in vascular resistance can be indicated by variations in peripheral pulse amplitude, where decreased pulse amplitude indicates vasoconstriction and increased vascular resistance (Iani, Gopher & Lavie, 2004). These physiological measures could be used to provide corroborative physiological evidence and hence stronger support for either of the aforementioned psychological accounts of the competition–performance relationship.

The Present Study

Informed by previous research, the purpose of the present experiment was to evaluate the potential mediating roles of enjoyment, anxiety and effort on the competition–performance relationship. To advance previous work, self-report measures were supplemented with objective physiological measures of emotional reactivity (i.e., challenge and threat appraisals) (Jones et al., 2009). To date, few other studies have applied such an interdisciplinary approach to the competition performance relationship (e.g., Cooke et al., in press).

As a second important feature, a handgrip endurance task was employed. This was firstly to examine the generalisability of enjoyment as a mediator of performance across multiple tasks (cf. Tauer & Harackiewicz, 2004). Secondly, this task was chosen to provide a stringent test of enjoyment as a potential mediator of performance, because previous research has shown isometric contractions to be painful (e.g. Voor, Lloyd & Cole, 1969). This feature guards against the potential confound of enjoyment being elicited by the task rather than by the competition process. However, in adopting an endurance task, cardiovascular indices of challenge and threat appraisals may be masked by cardiovascular effects elicited by metabolic demands associated with the task. As a consequence, muscle activity was also measured, thus allowing an evaluation the effects of competition aside from those caused by metabolic demands.

Finally, the type of competition was graded so as to include individual competition, one-on-one competition, and 2 vs. 2 and 4 vs. 4 team competitions. Previous research has indicated that these conditions elicit a varying intensity of emotional responses, which is necessary to evaluate the potential mediating roles of emotions on performance (Baron & Kenny, 1986). Specifically, Tauer and Harackiewicz (2004) demonstrated that increased enjoyment typically occurs during team competitions compared to individual competitions. This is due to cooperation with team mates, and the sense of relatedness that this fosters. Similarly, Stephan, Stephan and Gudykunst (1999) suggested that anxiety might also increase when individuals are placed in intergroup conditions (i.e., teams) due to worries such as not being able to behave competently.

It was hypothesised that self-reported ratings of enjoyment, anxiety, and the associated effort, would increase from individual through one-on-one, to 2 vs. 2 and 4 vs. 4 team competitions (cf. Stephan et al., 1999; Tauer & Harackiewicz, 2004). Moreover, it was predicted that the physiological measures would indicate reactivity consistent with varying levels of challenge or threat appraisals, depending on whether positive or negative emotions have a more dominant influence on performance (cf. Jones et al., 2009).

If performance was to improve from individual to team competitions, physiological responses consistent with a challenge appraisal were expected. Moreover, it was hypothesised that performance would be mediated by increased enjoyment (Tauer &

Harackiewicz, 2004) or increased effort (Eysenck & Calvo, 1992). Finally, if performance was to deteriorate from individual to team competitions, physiological responses were expected to indicate a threat appraisal, and performance was expected to be mediated by increased anxiety (Eysenck & Calvo, 1992).

Method

Participants, Task and Design

Sixty-four (32 men, 32 women) healthy undergraduate students (*M* age = 20.7 years, *SD* = 1.3 years) participated in the experiment. They were required to squeeze a bespoke handgrip dynamometer (see Radwin, Masters, & Lupton, 1991) continuously, maintaining a grip force equivalent to at least 40% of their Maximum Voluntary Contraction (MVC) for as long as possible. A within-subject design was employed. Accordingly, participants completed the endurance task in individual, one-on-one, 2 vs. 2, and 4 vs. 4 competition conditions (see Experimental Conditions section below), with the order counterbalanced.

In each condition, participants sat upright and used their dominant hand to hold the dynamometer, which was supported so that their arm was flexed at approximately 100°. A dual-color light emitting diode panel positioned opposite each participant displayed grip force information. Green numbers indicated a force equal to or greater than 40% MVC. For example green 0 represented a grip-force equivalent to 40% MVC, green 1 represented a grip-force equivalent to 41% MVC, and so on. Red numbers indicated a grip-force below 40% MVC (red 1 = 39% MVC, red 2 = 38% MVC, etc). Participants were asked to maintain a grip force that ensured a low green number was displayed (i.e., to help ensure that the force maintained was close to the 40% MVC threshold) for as long as possible. The task terminated when grip force fell below 40% MVC for more than two seconds. Force data were recorded through an analogue-to-digital convertor (Power 1401, CED) and digitised at 2500 Hz with 16-bit resolution. Force and endurance time were recorded by a computer running Spike2 software.

Procedure and Questionnaires

Participants attended a two-hour testing session in single-sex groups of eight individuals. First, informed consent was obtained. Each participant was then assigned to an experimenter at one of eight stations arranged around the edge of the laboratory, where their MVC was recorded. Specifically, participants completed three maximal handgrip contractions, separated by three minutes of rest (Voor et al., 1969). MVC was classified as the largest (M = 458.2, SD = 127.9 N) of the three contractions (Voor et al., 1969).

After MVC was obtained, 40% MVC was calculated and entered into a bespoke computer program. The endurance task was then explained (see Task section). Participants then performed the task in a non-competitive "do your best" environment. They were then re-assigned to a station, based on their "do your best" endurance time (i.e., participant with longest endurance time was assigned to station one; participant with second longest endurance time went to station two, and so on). Pilot testing indicated that this endurance pre-test, and the station layout that was adopted (see Figure 5.1), would ensure that all competitions (described below) were closely fought.

Following this re-assignment, instrumentation for the recording of physiological signals took place. Participants then sat quietly during a 5-minute formal rest period to allow baseline physiological data to be acquired (see Data Reduction section). Following the rest, participants were informed of the competition in which they were to compete first, (i.e., individual, one-one-one, 2 vs. 2 or 4 vs. 4). They then completed the task in this condition.

This was followed by a 5-minute recovery period during which participants were asked to rate their levels of enjoyment, anxiety and effort during the previous condition.

The 7-item enjoyment subscale of the Intrinsic Motivation Inventory (Ryan, 1982) was used to measure enjoyment. Items, including “It was fun to do”, were rated on a 7-point Likert scale, with anchors of 1 (*not at all true*)*,* 4 (*somewhat true*)*,* and 7 (*very true*). To measure anxiety, participants were asked to rate how they felt on an 11-point scale anchored with the terms *calm* and *worried* (Krane, 1994). Finally, participants were asked to rate the level of effort that they expended using a vertical axis scale ranging from 0–150, with nine category anchors, including, 3 *(no effort at all)* and 114 *(extreme effort)* (cf. Zijlstra, 1993). Physiological data were recorded continuously during each condition.

This sequence (i.e., rest, instruction, task, recovery) was then repeated in the remaining counterbalanced conditions. At the end of the session, participants were thanked, debriefed, and asked not to disclose information of the experiment with others.

Experimental Conditions

Individual competition. Participants were informed that they were competing against all other participants in the study, and that their endurance time would be ranked on a leaderboard listing all participants. Moreover, the leaderboard would be circulated to all participants at the end of the study.

One-on-one competition. In this condition, participants began the isometric contraction simultaneously with a rival who was positioned directly opposite (i.e., station 1 vs. station 2, station 3 vs. station 4, and so on). Participants were told that they were in competition with their rival to see who could maintain endurance for the longest period.

2 vs. 2 team competition. Here, participants were paired up, and competed directly against a rival pair, who simultaneously completed the endurance task, and were positioned directly opposite (i.e., stations 1 and 4 vs. stations 2 and 3; stations 5 and 8 vs. stations 6 and 7). Participants were told that they were in competition with the opposing team to see which pair could achieve the most points. Specifically, points were allocated at a rate of one per second for each member of the team that was maintaining the required force. Points were displayed on a master computer that updated the score in real time (Figure 5.1).

4 vs. 4 team competition. This condition was the same as the 2 vs. 2 team condition, except that participants were now in teams of four (i.e., stations 1, 4, 5 and 8 vs. stations 2, 3, 6 and 7).

It should be noted that in the one-on-one and the team competition conditions, participants were asked to maintain the contraction for as long as possible, even when their opponent had been eliminated. To emphasize the importance of this feature, participants were informed that leaderboards displaying the best performers in the one-on-one and team conditions would also be produced at the end of the study.

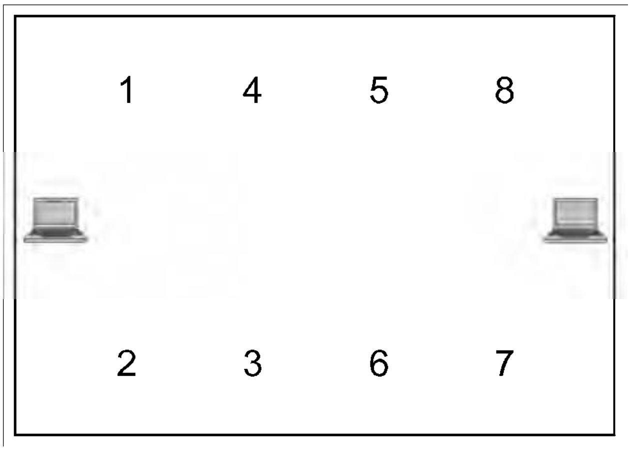

Figure 5.1. Laboratory plan to depict the layout of the numbered stations and the position of the computers used to allocate points during team competitions.

Physiological Measures

Cardiovascular activity. An electrocardiogram was obtained using three silver/silver chloride spot electrodes (Cleartrace, ConMed) in a modified chest configuration. Active electrodes were positioned on the right clavicle and a lower left rib with a reference electrode positioned on the left clavicle. The electrocardiographic signal was amplified and filtered (0.1–300 Hz plus 50 Hz notch filter) by an AC amplifier (LP511, Grass). Heart rate was derived from the intervals between R-waves of the electrocardiogram.

In addition, an infrared photoplethysmograph (1020 EC, UFI) was used to measure pulse at the right ear. The pulse signal was amplified by a custom made amplifier with a gain of 100 and a bandwidth of 0.06 to 35 Hz. The R-wave to ear pulse interval was calculated as the time between the peak of the R-wave of the electrocardiogram and the foot of the systolic upstroke of the ear pulse. The foot was defined as the point when the slope of the pulse upstroke was 25% of the maximum slope of that upstroke (Lane, Greenstadt, Shapiro, & Rubinstein, 1983).

Finally, the amplitude of the pulse wave was recorded to indicate vascular resistance (Iani et al., 2004). Pulse amplitude was computed as the difference between the foot and peak of the pulse waveform.

Muscle activity. Electromyographic activity was recorded in the extensor carpi radialis muscle which is used for gripping, in both the dominant and non-dominant forearm. These sites were chosen to indicate the physical demands of the task (i.e., activity in the dominant arm) and any general muscular tension that was elicited by the conditions (i.e., activity in the non-dominant arm). Differential surface electrodes mounted together with a reference electrode in a case containing a ×1000 pre-amplifier were used to record electromyographic activity. Two active electrodes, separated by 15 mm, were oriented longitudinally along the muscle with the reference electrode positioned between the two active electrodes and offset 10 mm laterally (Johnson, Lynn, Miller, & Reed, 1977). Conductive cream was applied to the electrode contacts. The electromyographic signal was amplified (×2) and filtered (10 – 1000 Hz) by a custom made amplifier.

To improve the fidelity of all physiological signals, recording sites were exfoliated (Nuprep, Weaver) and degreased with alcohol wipes (Sterets, Medlock) prior to electrodes being affixed. Data were acquired through a Power1401 (CED) by a computer running Spike2 software. All signals were digitised at 2500 Hz with 16-bit resolution.

Data Reduction

Values to represent mean physiological activity at baseline and in the four competition conditions were calculated. Baseline activity was calculated during the final (i.e., fifth) minute of the rest period that preceded the first condition. Baseline activity was assessed to illustrate physiological reactivity, thus allowing the identification of activation patterns consistent with challenge and threat appraisals (Jones et al., 2009).

Statistical Analysis

Pulse data from three participants were unscorable, thus, the R-wave to pulse interval and pulse amplitude could only be calculated for 61 of the 64 participants. Data from all participants were included when analysing the other variables. Exploratory analysis of the data, which included sex as a between-subject factor, revealed a sex main effect on endurance performance. This effect $F(1, 62) = 7.34$, $p < .01$, $\eta_p^2 = .11$, demonstrated that females tended to achieve greater endurance times ($M = 95.94$, $SD = 32.78$ seconds) than males ($M = 80.24$, $SD = 32.78$ seconds). Such an effect is commonly reported during isometric contractions (for discussion see Hunter & Enoka, 2001). Importantly, there was no sex by condition interaction effect on endurance performance, $F(3, 60) = 0.57$, $p = .64$, $\eta_p^2 =$

.03. Moreover, no sex or sex by condition interaction effects were found in any of the other variables. Accordingly, the effects of the experimental manipulations were similar for both males and females, so the analyses reported do not include sex as a factor.

Performance and questionnaire measures. A 4 condition (individual competition, one-on-one competition, 2 vs. 2 competition, 4 vs. 4 competition) repeated measures MANOVA to examine the effects of condition on the performance and questionnaire measures was conducted first. Significant multivariate effects were followed by separate repeated measures ANOVAs for each variable. Significant ANOVA effects were followed by LSD post hoc comparisons where appropriate. Partial eta-squared (η_p^2) is reported as a measure of effect size. Values of .02, .13 and .26 for η_p^2 indicate small, medium and large effect sizes, respectively (Cohen, 1992).

Physiological measures. First, a 5 condition (baseline, individual competition, one-on-one competition, 2 vs. 2 competition, 4 vs. 4 competition) repeated measures MANOVA was conducted to examine challenge and threat appraisals and the physiological impact of the tasks. This was followed by separate repeated measures ANOVAs and post hoc comparisons, as described previously.

Mediation analyses. Regression analyses were used to examine mediation. Due to the within-subjects design, the difference/sum regression procedure outlined by Judd, Kenny, and McClelland (2001) was followed. This procedure and the results of these analyses are presented in the results section.

Results

Performance and Questionnaire Measures

A 4 condition repeated measures MANOVA examined the effect of condition on the performance and questionnaire measures. This analysis revealed a multivariate effect for condition, $F(15, 49) = 6.08$, $p < .001$, $\eta_p^2 = .65$.

Subsequent 4 Condition ANOVAs revealed a main effect of condition on endurance performance. Endurance time was shortest during the individual competition and greatest during the team competitions (Table 5.1). ANOVA found no main effect of condition for force maintained. Participants maintained a grip force that was very close to 40% MVC in all conditions (Table 5.1).

Finally, ANOVAs confirmed that ratings of enjoyment, anxiety and effort increased from the individual competition to the one-on-one competition, and again to the two team competitions (see Table 5.1).

Physiological Measures

A 5 condition repeated measures MANOVA examined the physiological impact of the competitions. This analysis revealed a multivariate effect for condition, $F(20, 41) = 47.50$, $p < .001$, $\eta_p^2 = .96$.

Subsequent 5 Condition ANOVAs revealed that heart rate increased from baseline to each of the competition conditions, and was greatest in the 2 vs. 2 competition. Inversely, R-wave to pulse interval decreased from baseline to each of the competition conditions, and was smallest in the 2 vs. 2 competition (Table 5.2). These data indicate an increase in sympathetic activation from baseline to the competition conditions, with the greatest increase in reactivity occurring during the 2 vs. 2 competition.

Table 5.1: *Effects of Competition on Performance and Questionnaire Measures*

Measure	Condition									
	Individual Competition		One-on-one Competition		2 vs. 2 Competition		4 vs. 4 Competition		*F* (3, 61)	η_p^2
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Endurance time (seconds)	68.80	37.75	88.11^{a}	42.10	$101.51^{a,b*}$	37.79	93.94^{a}	39.57	13.05***	.39
Force (% MVC)	40.75	1.49	41.10	1.70	40.89	1.30	40.89	1.40	1.59	.07
Enjoyment (1-7)	3.26	1.05	3.85^{a}	0.98	$4.15^{a,b}$	1.12	$4.23^{a,b}$	1.14	13.22***	.39
Anxiety (1-11)	4.34	1.77	5.25^{a}	2.09	$5.45^{a,b}$	2.11	$5.91^{a,b,c}$	1.97	14.27***	.41
Effort (0-150)	74.83	26.79	88.88^{a}	19.25	92.70^{a}	20.61	93.31^{a}	18.24	10.56***	.34

Note: $^{a,\,b}$ and ^{c} indicate significant differences (p <.05) from the individual, one-on-one, and 2 vs. 2 competition conditions, respectively.
$^{b*}p$ <.07, $^{***}p$ <.001

Table 5.2: *Effects of Competition on Physiological Measures*

Measure	Condition											
	Baseline		Individual Competition		One-on-one Competition		2 vs. 2 Competition		4 vs. 4 Competition		$F(4, 60)^{\#}$	η_p^2
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*		
Heart rate (bpm)	73.97	11.10	94.28^{a}	16.48	104.29^{b}	17.81	$108.84^{a,b,c}$	16.45	$105.81^{a,b,d}$	17.27	142.20***	.91
R-wave to pulse interval (ms)	162.51	17.76	142.29^{a}	16.18	$132.04^{a,b}$	15.92	$128.95^{a,b,c}$	17.01	$132.40^{a,b,d}$	17.14	93.55***	.87
Pulse amplitude (mV)	1.95	1.40	1.89	1.23	2.08	1.38	1.91	1.20	1.91	1.17	0.69	.05
Dominant arm EMG activity	26.53	45.30	407.68^{a}	303.04	$438.12^{a,b}$	325.41	$443.31^{a,b}$	331.73	$442.15^{a,b}$	337.33	29.67***	.64
Non-dominant arm EMG activity	20.46	10.82	33.73^{a}	36.31	39.81^{a}	51.94	39.38^{a}	35.21	35.95^{a}	31.89	5.45***	.27

Note: $^{a, b, c}$ and ^{d} indicate significant differences (p <.05) from the baseline, individual, one-on-one, and 2 vs. 2 competition conditions, respectively. ***p <.001, $^{\#}$ F(4, 57) for R-wave to pulse interval and pulse amplitude.

ANOVA revealed no effect of competition on pulse amplitude (Table 5.2). This finding indicates that competition had no notable effect on peripheral vascular resistance.

5 Condition ANOVAs to assess muscle activity in the dominant arm revealed an increase from baseline to the individual competition condition, and again to the other three conditions, which did not differ. Muscle activity in the non-dominant arm increased from baseline to the competition conditions, which did not differ (Table 5.2).

Taken together, the physiological data indicate that competition increased sympathetic activation over and above the between-condition differences in metabolic demands (i.e., cardiovascular variables differed between the one-to-one, 2 vs. 2, and 4 vs. 4 conditions, despite muscle activity being the same).

Mediation Analyses

To examine mediation, Judd et al.'s (2001) difference/sum regression procedure, which is used with repeated measures designs, was followed. To conduct these analyses, there must be condition differences in the dependent variable (endurance time) and potential mediator variables (i.e., enjoyment and effort). Accordingly, separate sets of analyses were conducted to examine mediators of the difference between performance recorded in the individual competition condition and a) the one-on-one competition; b) the 2 vs. 2 competition; and c) the 4 vs. 4 competition.

Regression analyses were conducted to predict the difference in endurance time between one-on-one/ 2 vs. 2/ 4 vs. 4 competition conditions and the individual competition from (a) the difference in enjoyment and effort across these conditions and (b) the mean centred sum of enjoyment and effort in the these conditions. Mediation can be inferred if the condition difference in enjoyment or effort predicts the difference in endurance time (Judd et al., 2001). The residual difference, indicated by the unstandardised *b,* represents any variance over and above mediation.

The results of these analyses are presented in Table 5.3. In brief, they indicated that the variance in endurance time was significantly reduced when enjoyment and effort were included in the regression equations, providing evidence for mediation. However, in each case enjoyment accounted for more variance than effort, indicating that this was the strongest mediator.

Discussion

Previous research has identified enjoyment, anxiety and effort as factors that could underlie the effects of competition on performance (e.g., Eysenck & Calvo, 1992; Tauer & Harackiewicz, 2004). This study is one of the first to statistically examine these variables as mediators of the effects of competition on performance.

To examine the effects of competition, endurance performance was assessed in four competition conditions (i.e., individual; one-on-one; 2 vs. 2; 4 vs. 4). Results indicated that endurance performance was worse during the individual competition, and best in the team competition conditions, demonstrating the potential for different competitions to elicit effects on performance (Stanne et al., 1999).

Based on the findings of Tauer & Harackiewicz (2004) and the suggestions of Stephan et al. (1999), it was hypothesised that enjoyment, anxiety and effort would increase from the individual through to the team competition conditions. These hypotheses were supported, confirming that different competitions elicit emotional responses of varying intensity. Tauer and Harackiewicz (2004) demonstrated that increased enjoyment occurs

Table 5.3: *Mediators of Performance*

Conditions	Original difference in endurance time (seconds)	Test for mediation			Residual difference in endurance time after mediation (seconds)
		Variable	*b*	*t*(61)	
Individual – one-on-one competition	19.31				
		Enjoyment	26.83	4.68***	3.44
		Effort	.81	3.50***	7.99
Individual – 2 vs. 2 competition	32.71				
		Enjoyment	18.93	4.93***	15.80**
		Effort	.56	2.60*	22.79***
Individual – 4 vs. 4 competition	25.14				
		Enjoyment	25.41	5.34***	0.53
		Effort	.55	2.11*	14.90

Note: *p <.05, **p ≤.01, ***p ≤.001.

during team competitions due to the cooperation with team mates, and the sense of relatedness that this fosters. Similarly, Stephan et al. (1999) suggested that anxiety increases when individuals are placed in intergroup conditions due to worries such as not being able to behave competently.

To provide a comprehensive assessment of the effects of competition on emotions, physiological measures were used to indentify challenge appraisals, which are associated with positive emotions, and threat appraisals, which are associated with negative emotions. Challenge appraisals are characterised by increased sympathetic activation and decreased vascular resistance, whereas threat appraisals are characterised by smaller increases in sympathetic activation, and unchanged or increased vascular resistance (Jones et al., 2009). As performance improved from the individual competition to the other competition conditions, patterns of cardiovascular activity consistent with a challenge appraisal were expected during these conditions.

Contrary to expectations, the null effect of competition on pulse amplitude suggested that vascular resistance was unchanged by competition. However, sympathetic activation was increased, as indicated by increased heart rate and decreased R-wave to pulse interval. In particular, sympathetic activity increased more from baseline to one-on-one, 2 vs. 2, and 4 vs. 4 competition conditions, compared to the individual condition. Moreover, sympathetic activity was greatest in the 2 vs. 2 team competition, despite the metabolic demands, which have a potential confounding influence on sympathetic activity, being the same across one-on-one and the two team competitions. This pattern of responding provides corroborative and hence stronger evidence that competitions elicit emotional responses (cf. Obrist, 1981). Moreover, it suggests that participants made a threat appraisal during competitions, although this appraisal shifted more towards a challenge appraisal (i.e., greater sympathetic activity), particularly during the 2 vs. 2 competition, where performance was best.

Threat appraisals are generally associated with negative emotions (Jones et al., 2009), so these physiological data suggest that anxiety might have mediated performance. However, the performance data suggest that this should not be the case, as anxiety is not normally considered to underlie improved performance. Rather, improved performance with increases in anxiety should be mediated by increased effort (cf. Eysenck & Calvo, 1992). Future research could use additional physiological measures of sympathetic activity and vascular resistance (e.g., total peripheral resistance) to more fully assess challenge and threat appraisals during competition.

Mediators of the Effects of Competition on Performance

It was hypothesised that enjoyment (Tauer & Harackiewicz, 2004) or effort (Eysenck & Calvo, 1992) would mediate any facilitative effects of competition on performance. Mediation analyses revealed that both variables significantly reduced the variance in performance. However, enjoyment was a stronger mediator, as it always reduced the residual variance by more than half. This finding extends the results of Tauer and Harackiewicz (2004) by confirming their result using a different task. It also sits well with Fredrickson's (2004) broaden-and-build theory of positive emotion, which contends that positive emotions produce optimal performance (Fredrickson, 2004). According to Fredrickson, positive emotions have a positive effect by broadening thought-action repertoires and building personal resources, for example, psychological resilience. A joy fuelled increase in resilience could explain the improvement in performance from individual competition to the other conditions. This is because resilience would seemingly be required to improve performance when faced with increased anxiety and the pain associated with isometric contractions (Voor et al., 1969). Future research could examine this suggestion.

As effort also mediated performance, this experiment provides one of the first datasets to demonstrate this hypothesised relationship (cf. Cooke et al., in press), which is in accordance with processing efficiency theory. According to processing efficiency theory, increased effort improves performance by allocating additional attention to a task (Eysenck & Calvo, 1992). However, future research that incorporates measures of attentional capacity and resource allocation is required for this mechanism to be confirmed.

Conclusion

In conclusion, the results of this experiment provide further evidence to demonstrate that competitions elicit effects on performance. Specifically, performance improved from individual to team competitions. Previous research was extended by the assessment of physiological indices of emotion during competition, and by the statistical evaluation of putative mechanisms of the facilitative effects of competitions on performance. Physiological data provided corroborative evidence that competitions elicit emotional responses, and indicated increased sympathetic activation during team competitions. In addition, team competitions elicited increased levels of enjoyment and effort among participants, both of which served to mediate improved performance. Importantly, enjoyment accounted for a greater proportion of the variance in endurance performance than effort, supporting a positive emotion account (e.g., Fredrickson, 2004; Tauer & Harackiewicz, 2004) of the competition–performance relationship. It remains for future research to pursue this exciting interdisciplinary approach and add more detail to our knowledge of the relationships between competition, emotions, and performance.

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CHAPTER SIX

General Discussion

The aim of this thesis was to increase our understanding of the psychological and physiological processes that underlie the effects of competition on performance. The purpose of this final chapter is to summarise the findings of each experiment, and outline the theoretical implications of the research. In doing so, this chapter evaluates the success of the research program in advancing our understanding of the competition–performance relationship. Finally, it outlines suggestions for future research, to further advance our knowledge in this exciting field.

A Summary of Aims and Findings

The aim of chapter one was to demonstrate the potential for competition to effect performance. It also outlined theories which may provide insights into the mechanisms that underpin the competition–performance relationship. Accordingly, the effects of competition on performance were reviewed, and processing efficiency theory, reinvestment theory, and an enjoyment model were highlighted as potential theoretical explanations of these effects. An outline of how physiological and kinematic measures could be incorporated in an interdisciplinary approach to studying the effects of competition on performance was also provided. The advantages of this approach, such as providing a more comprehensive analysis of the effects of competition, and generating corroborative and hence stronger support for theoretical predictions, were also described. Finally, a rationale for applying mediation analyses to statistically evaluate variables as mechanisms that cause competition-induced changes in performance was explained.

Adopting this interdisciplinary and mediational approach, the experiment reported in chapter two concurrently examined psychological, physiological and kinematic responses to, as well as performance under multiple levels (low, medium, high) of competitive pressure. The aim of this experiment was to test the predictions of processing efficiency theory. The primary purpose was to examine whether increased competitive pressure was associated with changes in performance and to formally evaluate possible causes using mediation analyses. A golf putting task was employed and novice golfers were recruited as participants. Results indicated that fewer putts were holed with increased competitive pressure. Moreover, competitive pressure elevated anxiety, effort, heart rate, heart rate variability, muscle activity and lateral clubhead acceleration. Mediation analyses revealed that effort, muscle activity and lateral clubhead acceleration were responsible for the decline in performance. These findings provided limited support for processing efficiency theory, and instead were interpreted through reinvestment theory. However, it was conceded that an expert population is required to optimally test the predictions of reinvestment theory, as experts have the most room to regress under pressure (Fitts & Posner, 1967).

Accordingly, to build on the findings reported in chapter two, the experiment reported in chapter three concurrently examined expert golfers' psychological, physiological, kinematic and performance responses to competitive pressure. By using expert golfers as participants, the study was able to examine the predictions of processing efficiency theory and reinvestment theory. Again, the primary purpose was to establish causes of competition-induced changes in performance through mediation analyses. Results of this study indicated that competitive pressure improved performance, in terms of how close putts finished to the hole. Moreover, increasing competitive pressure elevated anxiety, effort and heart rate, and decreased grip force. Quadratic effects were noted for conscious processing and impact velocity, where impact velocity was greater, and conscious processing was reduced during medium-pressure. Mediation analyses revealed that effort and heart rate partially mediated improved performance. The results were interpreted through reinvestment theory and processing efficiency theory.

To continue pursuing this interdisciplinary approach, but consider the effects of competition on a different task, the experiment reported in chapter four examined the effects of competition on endurance performance. It included self-report and some objective physiological measures of emotional state to test the predictions of processing efficiency theory and an enjoyment-based model (e.g., Tauer & Harackiewicz, 2004) of the competition–performance relationship. A handgrip endurance task was employed, and undertaken by participants in a competitive and a non-competitive condition. Results indicated that endurance performance was greater during competition. Moreover, competition increased anxiety, effort, enjoyment, heart rate and muscle activity, and decreased heart rate variability, R-wave to pulse interval and pulse amplitude. Enjoyment fully mediated whereas effort and heart rate variability partially mediated the effects of competition on performance. In addition, anxiety moderated the competition–performance relationship; those with lower anxiety performed better in competition. These findings provided some support for processing efficiency theory and an enjoyment model of the competition–performance relationship. However, potential limitations of this experiment were acknowledged. For instance, competition was only compared with a non-competitive condition. Moreover, the competition manipulation may have been confounded by the evaluative audience that was introduced in the competition condition.

To address some of these limitations and build on chapter four, the experiment reported in chapter five examined the effects of different types of competition (i.e., individual and team) on performance. This experiment was designed to further evaluate processing efficiency theory and an enjoyment model as accounts of the competition–performance relationship. The same handgrip endurance task as was used in chapter four was employed, with endurance time serving as the measure of performance. Endurance performance was better, and enjoyment, anxiety, effort, and sympathetic activity were greater during team competitions. Physiological data confirmed the presence of negative emotions during competitions. However, mediation analyses revealed that enjoyment and effort (to a lesser extent) were the key variables responsible for mediating the effects of competition on performance. These results provided further support for processing efficiency theory and an enjoyment model.

Theoretical Implications

These findings are now discussed collectively, in terms of the predictions made by processing efficiency theory, reinvestment theory, and an enjoyment model.

Processing Efficiency Theory

In examining processing efficiency theory as a mechanistic explanation of the effects of competition on performance, the experiments that are reported were able to test the following hypotheses: a) competition should increase anxiety and effort; b) increased anxiety should mediate impaired performance during competition; c) increased effort should mediate improved performance during competition; d) increased anxiety should mediate increased effort; e) anxiety should moderate the effects of competition on performance. Each of these predictions is now discussed.

a) Competition should increase anxiety and effort.

Unequivocal support was generated for this prediction. This further highlights the potential of processing efficiency theory as an explanation of the effects of competition on performance as it confirms that anxiety and effort are prominent in competitive environments (cf. Woodman & Hardy, 2001).

b) Increased anxiety should mediate impaired performance during competition.

Only in the experiment described in chapter two was performance significantly impaired with increased competitive pressure. Specifically, novice golfers holed fewer putts during medium and high-pressure conditions than during a non-competitive low-pressure condition. Mediation analyses demonstrated that increased anxiety with elevated competitive pressure was not responsible for the observed competition-induced impairment in putting performance. This finding does not support the prediction made by processing efficiency theory. However, it is conceded that anxiety was measured pre-performance, and perhaps a measure of anxiety felt during performance is required to best examine this prediction. In the remaining experiments, anxiety was assessed during performance, however, competition did not impair performance in the experiments reported in chapters three, four, and five, and accordingly, this prediction of processing efficiency theory could not be examined further.

Nevertheless, it was speculated that anxiety could explain the trend for more putts to be holed during medium-pressure compared to high-pressure in chapter three. Specifically, greater anxiety in the high-pressure condition could have overloaded the central executive and caused performance to reduce from medium to high-pressure, despite increased effort. Unfortunately, mediation analyses could not be applied to examine this hypothesised relationship due to the overall null effect of pressure on outcome performance (i.e., the dependant variable) (Baron & Kenny, 1986). An alternative account of this finding is also offered by reinvestment theory (see below).

c) Increased effort should mediate improved performance during competition.

Performance was improved with increasing competition in the experiments reported in chapters three, four and five. Specifically, expert golfers putted balls closer to the hole during medium and high-pressure conditions compared to a non-competitive low-pressure condition (Chapter 3). Moreover, participants increased their isometric handgrip endurance time from a non-competitive to a competitive condition (Chapter 4), and from an individual competition to one-on-one and team competitions (Chapter 5). In all cases, mediation analyses confirmed that effort was at least partially responsible for the observed facilitative effects of competition on performance. These findings support the notion that effort is important in improving performance during competition. However, processing efficiency theory's suggestion that effort should be beneficial by increasing the number of processing resources allocated to a task could not be confirmed. To gain evidence to support this prediction, an examination of processing capacity and resource allocation is required. In an attempt to retain ecological validity within the competition manipulations, the reported experiments avoided incorporating dual-task or attentional probing techniques that would be required to examine processing capacity and resource allocation (cf. Gray, 2004). As effort has now been demonstrated to drive improvements in performance, such future studies are warranted.

d) Increased anxiety should mediate increased effort.

Given the number of variables that were measured and considered as mediators in the previously reported experimental work, only analyses where performance was the dependant variable were reported. However, mediation analyses were also performed to examine whether increased effort was driven by increased anxiety. Increased anxiety did not mediate increased effort in the experiments reported in chapters two, three (both golf putting) or four (handgrip endurance). However, anxiety did partially mediate increased effort from the individual competition condition to the other competition conditions in the final handgrip experiment that is reported in chapter five. The results of these supplementary analyses are presented in Appendix 1A, 1B, and 1C.

The discrepancy between chapter five, where anxiety did mediate effort, and the earlier chapters, where anxiety did not mediate effort, could be explained by differences in the experimental manipulations. Specifically, the competition manipulations in chapters two, three and four all included monetary rewards for those that won the respective competitions. This feature of the competition manipulation was not included during the experiment reported in chapter five. It seems that anxiety is more likely to mediate effort when external rewards are not present (cf. Brehm, 1999). In contrast, when such rewards are present, as is often the case in competitive sports, these factors might override the effects of anxiety on effort. In other words, effort might be promoted by an increase in the value of success (i.e., the presence of monetary reward) rather than by an increase in worrisome thoughts associated with competition (Wright, Killebrew & Pimpalapure, 2002).

Accordingly, processing efficiency theory may provide a better explanation of the anxiety–performance relationship in the cognitive domain (e.g., academic tests), than in the sports domain, where competitions traditionally offer more external rewards (e.g., prize money, trophies, medals) for success (cf. Eysenck & Calvo, 1992). Future research is required to further examine the mediators of increased effort.

e) Anxiety should moderate the effects of competition on performance.

A final suggestion of processing efficiency theory is that anxiety might moderate performance. Specifically, when anxiety levels are low, an individual should be capable of improving performance to a greater extent than when anxiety levels are high. This is because less anxiety should leave more processing resources available, which can be focused on task performance through increased effort (Eysenck & Calvo, 1992). A regression approach to mediation permits tests of moderation (Judd, Kenny & McClelland, 2001), and accordingly, allows an examination of this suggestion. A regression approach was employed and moderation analyses were conducted in chapter four and chapter five.

Regression analyses yielded some support for the suggestion that anxiety should moderate performance. Specifically, anxiety did moderate performance in the expected fashion in the experiment reported in chapter four. In chapter five, moderation analyses were not reported, however, they are presented in Appendix 1D. They revealed that anxiety did not moderate the difference in performance between the individual and the one-on-one competitions, and between the individual and the 2 vs. 2 competitions. In contrast, anxiety did moderate the difference in performance between the individual and the 4 vs. 4 competition conditions.

Finally, for consistency across all experiments, the data yielded in chapters two and three, which were originally analysed by ANCOVA, were re-analysed to test for moderation as per the regression procedure adopted in chapter five. These analyses revealed no evidence for anxiety moderating golf putting performance (see Appendix 1E, 1F).

Taken together, these results clearly offer only mixed support for the prediction that anxiety should moderate performance. Importantly, support for this prediction was generated when participants performed in competitions when multiple team mates were present and were simultaneously performing the task (i.e., in chapter four and in the 4 vs. 4 competition in chapter five). It is noteworthy that these conditions generated the highest anxiety levels. Thus, it seems that anxiety is more likely to moderate performance when greater anxiety is elicited, particularly by greater social comparison in team conditions (cf., Stephan, Stephan & Gudykunst, 1999).

Processing Efficiency Theory: Insights from Psychophysiological Measures

In addition to the self-report measures of anxiety and effort, physiological indices of these constructs were also employed to provide an interdisciplinary examination of processing efficiency theory. Specifically, heart rate variability was measured, as indexed by SDNN. SDNN is a time domain correlate of the frequency domain based low-frequency band (i.e., 0.04- 0.15 Hz) (Carrasco, Gaitan, Gonzalez & Yanez, 2001), which includes the 0.07-0.14 Hz component that is hypothesised to reflect variations in effort (Mulder, 1992). Decreased heart rate variability in this band has been argued to reflect increased effort (e.g., Jorna, 1992; Mulder, 1992). SDNN failed to decrease with competition, despite increases in self-reported effort, in the studies reported in chapter two and chapter three. It was suggested that the postural demands of golf putting masked any effects of effort on the cardiovascular system (Veldhuijzen van Zanten, Thrall, Wasche, Carroll & Ring, 2005). However, SDNN did decrease with competition in chapter four, and this effect was partially responsible for the observed facilitative effect of competition on endurance performance. If decreased SDNN reflects increased effort, then this finding would be supportive of processing efficiency theory. However, SDNN did not correlate significantly with self-reported effort (r's = .15 – .16, p's = .13 – .14), and, therefore, this remains speculative. It is conceded that a concurrent measure of ventilation is required for an optimal examination of the effects of psychological processes on heart rate variability (Mulder, 1992). Ventilation was not measured in any of the reported experiments, but should be assessed when examining heart rate variability as a physiological index of invested effort in the future.

In addition to heart rate variability, heart rate, which could reflect increased anxiety (e.g., Woodman & Davis, 2008), was also reported. In all experiments, heart rate increased alongside self-reported anxiety during competitions. However, heart rate is a crude measure that is influenced by numerous emotions (e.g., Kreibig, 2010). As increased heart rate was demonstrated to mediate the facilitative effect of competition on endurance performance that was noted in chapter four, it was suggested that heart rate was driven more by positive emotions than by anxiety (cf. Kreibig, 2010).

In an attempt to provide a more specific physiological measure of negative emotions such as anxiety, heart rate and the blood pressure pulse wave were considered concurrently in chapter five. Informed by the theory of challenge and threat appraisals in athletes (Jones, Meijen, McCarthy & Sheffield, 2009), it was noted that negative emotions such as anxiety are generally associated with threat appraisals. They can be indicated by an increase in cardiac sympathetic activation, coupled with no change in vascular resistance. The results reported in chapter five demonstrated a pattern of cardiovascular reactivity consistent with a threat appraisal, thus confirming the presence of negative emotions, during both individual and team competition conditions. However, as performance was improved, the negative emotions experienced were not examined as mediators of inferior performance under increased competitive pressure (cf. Eysenck & Calvo, 1992).

In sum, the reported experiments endeavoured to advance previous research by incorporating physiological measures of anxiety and effort, to provide an interdisciplinary examination of processing efficiency theory as a mechanism to explain the effects of competition on performance. Results demonstrated that it is difficult to implement heart rate variability as a reliable measure of effort during motor tasks, owing to confounds elicited by the metabolic demands associated with motor performance. Moreover, it is conceded that the concurrent measurement of ventilation is required to provide a comprehensive analysis of the heart rate variability signal.

Similarly, the results suggest that heart rate is a crude measure that is not specific enough to be a reliable indicator of anxiety (Kreibig, 2010). Markers of increased cardiac sympathetic activation coupled with unchanged vascular resistance might provide a better marker of negative emotions in general (Jones et al., 2009). This pattern of physiological responding was demonstrated in chapter five. However, competition had a facilitative effect on performance, providing no rationale for applying mediation analyses to examine physiological variables as mediators of performance (cf. Eysenck & Calvo, 1992). As a consequence, the physiological measures of anxiety and effort provided little corroborative support for processing efficiency theory as a mechanism of the effects of competition on performance.

Processing Efficiency Theory: A Summary

In sum, the results of the experiments that make up this thesis provide unequivocal support for the contention that competitions increase anxiety and effort. However, the predicted mediating role of anxiety in impairing performance under competitive pressure was not established. In contrast, support was generated for a different prediction of processing efficiency theory, namely, that effort should mediate any facilitative effects of competition. However, when probed further, it was found that when rewards were present within the competition, increased effort was not driven by increased anxiety as would be predicted by processing efficiency theory. Instead, it seems likely that the increase in effort was stimulated by the prospect of winning money. Putative physiological indices of anxiety and effort provided little corroborative support for processing efficiency theory. All in all, these results offer only limited support for processing efficiency theory as a mechanism to explain the effects of competition on performance in sport. Specifically, the putative role of anxiety, both on performance and in stimulating increases in effort, seems in need of revision.

Reinvestment Theory

In examining reinvestment theory as a mechanistic explanation of the effects of competition on performance, the experiments that are reported were able to test the following hypotheses: a) competition should increase anxiety and conscious processing; b) increased conscious processing should mediate impairments in the performance of experts during competition; c) increased anxiety should mediate increased conscious processing. Each of these predictions is now discussed.

a) Competition should increase anxiety and conscious processing.

As has been established, competition always elicited increases in anxiety. Conscious processing was only assessed in chapter three. The results of this experiment demonstrated a quadratic effect of competition on conscious processing. Conscious processing was lower during medium competitive pressure than during low and high-pressure conditions. These results confirm that levels of conscious processing can vary during different competition conditions, but question the contention that conscious processing should be mediated by anxiety (see below).

b) Increased conscious processing should mediate impairments in the performance of experts during competition.

Conscious processing was only assessed in the experiment reported in chapter three. Here, performance, as indexed by mean radial error, was facilitated with increases in competitive pressure. Accordingly, the prediction that increased conscious processing might cause impaired performance in experts could not be directly assessed.

However, a quadratic trend in the number of putts holed did indicate that more putts tended to be holed during the medium-pressure condition, which was when the level of conscious processing was attenuated. As discussed in chapter three, this finding seems supportive of the skill acquisition models (e.g., Fitts & Posner, 1967) which underpin reinvestment theory. Specifically, more putts tended to be made when participants adopted a less conscious and thus more automatic information processing strategy. However, as already noted, a different account of this finding can be offered by processing efficiency theory. Alternatively, if enjoyment was greater during the team competition that constituted the medium-pressure condition, this too could account for the trend of better performance during medium-pressure (cf. Tauer & Harackiewicz, 2004; Chapters 4 & 5).

Some final speculative support for the detrimental role of conscious processing on motor performance during competition was noted in the experiment reported in chapter two. Here, increased effort was partially responsible for impaired performance with increased competitive pressure. It is possible that an increase in effort reflects the mobilisation of conscious processing resources when performing motor tasks (cf., Eysenck & Calvo, 1992). However, when conscious processing and effort were both assessed in chapter three, effort did not display the same quadratic effect as was displayed by conscious processing. It may be fruitful for future research to further develop and examine the relationships between measures of conscious processing and measures of effort.

c) Increased anxiety should mediate increased conscious processing.

As noted previously, when conscious processing was assessed in chapter three, a quadratic effect of conscious processing was revealed, where conscious processing was lower during medium competitive pressure than during low and high-pressure conditions. However, anxiety increased in a linear fashion with increased pressure. This finding implies that conscious processing was not mediated by anxiety, in contrast to what is suggested by reinvestment theory. Although not presented in chapter three, supplementary analyses to examine anxiety as a mediator of conscious processing were conducted, and provided little evidence for this putative relationship (see Appendix 1G).

In sum, the evidence confirms that levels of conscious processing fluctuate during different competitions. However, anxiety was not the primary cause of variations in conscious processing. It is possible that conscious processing in experts is buffered by increased enjoyment, which may have been experienced during the medium-pressure condition (i.e., when conscious processing was reduced). This is because this condition represented a team competition, which often increases enjoyment, as chapters four and five demonstrate. It is intuitive that experts will be less likely to regress and consciously process an automatized skill when experiencing positive emotion. Unfortunately, positive emotions were not assessed in the experiment reported in chapter three, but such investigations in the future are warranted.

Reinvestment Theory: Insights from Psychophysiological and Kinematic Measures

In addition to the self-report measure of conscious processing, physiological and kinematic measures were recorded to provide an interdisciplinary examination of reinvestment theory. Specifically, muscle activity was measured to investigate the suggestion that adopting conscious control of movements could lead to a regression to a less efficient pattern of muscular activation (e.g., Weinberg & Hunt, 1976). The kinematics of the golf putter head were also measured in the experiments reported in chapter two and chapter three.

This was to examine the suggestion that increased conscious processing might lead to a more novice-like movement profile being displayed (e.g., Maxwell, Masters & Eves, 2003).

Results indicated an increase in muscle activity in the extensor carpi radialis muscle of the forearm during increased pressure in chapter two. This was attributed to tighter gripping of the club during increased competitive pressure, which is not normally advocated (cf. Pelz, 2000), and accordingly, could represent a regression to a less efficient stage of movement control. However, the participants in the experiment reported in chapter two were novices and as such, would have had little room to regress during competition. In chapter three expert golfers were recruited, but competition had no effect on the muscle activity of these experts. Finally, muscle activity was elevated during competition compared to no competition in the experiment reported in chapter four. However, an analysis of the profile of muscle activity within each condition indicated that this was not caused by an inefficient tensing of the muscle. Rather, the increase was driven by an elevation in muscle activity only in the final stages of the competitive contraction. This may have reflected additional effort during competition (cf. Eason, 1960).

With regard to movement kinematics, the experiment reported in chapter two demonstrated that increased competitive pressure increased the amount of lateral club-head acceleration. Mediation analyses confirmed that this effect was partially responsible for the observed impairment in putting performance with increased pressure. This could represent a regression to a sub-optimal movement profile during competition, which caused more putts to be missed wide of the hole. Similarly, in the experiment reported in chapter three, quadratic effects of pressure confirmed that competitive pressure again caused disruption to some of the kinematic measures. Specifically, the club was swung more slowly and less jerkily, and the ball was struck with a lower impact velocity in the medium-pressure condition. These are features of a more expert-like swing (Delay, Nougier, Orliaguet & Coello, 1997), which occurred in the condition where conscious processing was lowest. They thereby represent good evidence to indicate that variations in conscious processing might be reflected in motor tasks through variations in the kinematic profiles of actions.

In sum, the putative physiological and in particular the kinematic measures of conscious processing hold promise and could be used in future research to further explore the prediction that increased conscious processing should mediate impaired performance. Because competition generally facilitated performance in the experiments reported in this thesis, it was not possible to present strong support for this suggestion.

Reinvestment Theory: A Summary

In sum, the results of the reported experiments support the contention that competitions should increase anxiety. However, although competitions elicit variations in a performer's level of conscious processing, this does not follow the same pattern as anxiety. Instead, it seems that other factors such as positive emotion might also contribute to an explanation of the variance in conscious information processing during motor performance. As performance was facilitated with competition in the experiment reported in chapter three, the predicted mediating role of conscious processing in impairing performance under competitive pressure could not be established. However, indirect support for the skill acquisition models that underpin reinvestment theory was generated, as more putts tended to be holed when levels of conscious processing were lowest. Moreover, the kinematic measures seemed indicative of conscious processing, as they indicated a more expert-like golf swing when conscious processing was reduced. The nature of these results means only limited indirect support could be generated for reinvestment theory. However, these data indicate that increased anxiety is not the key mediator of increased conscious processing, and accordingly, this contention of reinvestment theory may require revision.

An Enjoyment Model

To examine enjoyment as a mechanistic explanation of the effects of competition on performance, the experiments that are reported were designed to test the following hypotheses: a) competition should increase enjoyment; b) increased enjoyment should mediate any facilitative effects of competition on performance. Each prediction is now discussed.

a) Competition should increase enjoyment.

Support was provided for this prediction. Enjoyment was greater during competition than during a non-competitive condition in the experiment reported in chapter four. Moreover, enjoyment also varied as a function of competition type in chapter five, with greater enjoyment being elicited in team competitions than in an individual competition. These findings confirm that competitions (particularly team competitions) can elicit positive emotion, in addition to the previously established negative emotions (i.e., anxiety). The robustness of this suggestion was further supported by the adoption of a painful and anxiety inducing isometric contraction task. This ruled out the potential confound of enjoyment being elicited by the task rather than by competition per se (cf. Tauer & Harackiewicz, 2004). These findings further highlight the potential of an enjoyment model as an explanation of the effects of competition on performance, as they confirm that enjoyment is prominent in competitive environments.

b) Increased enjoyment should mediate any facilitative effects of competition on performance.

Unequivocal support was generated for this prediction. Mediation analyses revealed that enjoyment mediated the facilitative effects of competition (compared to no competition) on endurance performance in chapter four. Moreover, enjoyment also mediated the beneficial effects of one-on-one, 2 vs. 2, and 4 vs. 4 competition conditions, compared to an individual competition, in chapter five. Although effort was also always a mediator of improved performance, enjoyment proved the stronger mediator in all cases. These data provide convincing evidence for the beneficial role of enjoyment in improving performance during competition. The mechanism through which enjoyment elicits beneficial effects on performance could not be ascertained from the data collected in this thesis. However, the broaden-and-build theory of positive emotion suggests that enjoyment could have a facilitative effect by increasing psychological resilience (Fredrickson, 2004). Future research could examine this suggestion.

An Enjoyment Model: Insights from Psychophysiological Measures

In addition to the self-report measure of enjoyment, physiological signals were also recorded to provide corroborative physiological evidence that competitions elicit positive emotions. Specifically, indices of sympathetic activation (i.e., heart rate, R-wave to pulse interval) and vascular resistance (i.e., pulse amplitude) were recorded to indicate challenge appraisals. Challenge appraisals are associated with positive emotions, and can be indexed by an increase in sympathetic activation coupled with a decrease in vascular resistance (Jones et al., 2009). Contrary to expectations, patterns of cardiovascular activity indicated a threat appraisal, which is associated with negative emotions, in both chapter four (i.e., increased sympathetic activation and increased vascular resistance) and chapter five (i.e., increased sympathetic activation and unchanged vascular resistance). These findings question the proposed indices of challenge appraisals or their association with enjoyment. This is because self-report data and observations made by the author clearly indicated the presence of enjoyment during handgrip competitions.

As previously acknowledged, heart rate is a crude measure associated with a range of emotions, including joy (Kreibig, 2010), so it is possible that elevated heart rate partially reflected increased enjoyment. Moreover, increased joy has also been tentatively linked to increased beta-adrenergic sympathetic activation (Kreibig, 2010). In both chapter four and chapter five, beta-adrenergic activation was increased during competition (i.e., increased heart rate and decreased R-wave to pulse interval) (cf. Veldhuijzen van Zanten, De Boer, Harrison, Ring, Carroll et al., 2002). In addition, increased happiness, a positive emotion related to joy, has been demonstrated to elevate alpha adrenergic sympathetic activation (Kreibig, 2010). Increased alpha adrenergic activation (i.e., decreased pulse amplitude) (Iani, Gopher & Lavie, 2004) occurred during competition in the experiment reported in chapter four.

These data demonstrate the complexities associated with assessing peripheral physiological signals to gain reliable indices of emotions. They could be argued to demonstrate some corroborative physiological evidence for the presence of positive emotions during competition (e.g., Kreibig, 2010), but could just as easily be argued as corroborative evidence for the presence of negative emotions (e.g., Jones et al., 2009). Future research utilising alternative measures of emotion (e.g., facial electromyographic activity or cortical asymmetry, see Cacioppo, Berntson, Larsen, Poehlmann & Ito, 2000) may add clarity to this field.

An Enjoyment Model: A Summary

In sum, the reported results support the contention that competitions can elicit positive emotions such as enjoyment, however, physiological evidence for positive emotions was mixed. Unequivocal support was found for the suggestion that increased enjoyment experienced during competitions should mediate the facilitative effects of competition on performance. These results provide good support for an enjoyment-based model as a mechanism of the effects of competition on performance. The onus is now on future research to incorporate these findings into a more comprehensive theory of how positive emotions such as enjoyment might influence the performance of a range of tasks (cf. Fredrickson, 2004).

Limitations of the Research

Although the experiments reported in this thesis were designed to advance previous research (e.g., by applying mediation analyses and by adopting a multi-measure approach), some limitations remained. Some of these limitations, such as potential floor effects in performance, and issues concerning the mixture of evaluation and rewards within competition manipulations, were presented in the discussions of the experimental chapters. However, there are three limitations that have not been previously acknowledged.

First, it is conceded that processing efficiency theory should have most relevance, when considered as a potential explanation for the effects of competition on performance, to tasks which place demands on the attentional system. Accordingly, the handgrip endurance task adopted in the experiments reported in chapter four and chapter five was perhaps not best suited to examine processing efficiency theory. This is because it can be argued that physical endurance tasks have few attentional demands. However, research has indicated that endurance tasks do have an attentional component, as the attentional system is used to process afferent signals representing peripheral physiological changes (e.g., levels of peripheral metabolites and cardiovascular activity) that allow an individual to decide when exercise should cease (St Clair Gibson, Baden, Lambert, Lambert, Harley et al., 2003). Thus, I would argue that processing efficiency theory does have some relevance to endurance performance. It is conceded however that motor tasks such as those which require aiming and precision are likely to be more attentionally demanding than endurance tasks, and therefore better equipped to test the predictions of processing efficiency theory in sport. Future research to examine processing efficiency theory could measure attentional capacity and resources to quantify the attentional demands of various tasks.

Second, measurement issues could limit the accuracy of the mediation models that were presented throughout the thesis. Issues relating to the measurement of self-report variables have long been debated by psychologists and statisticians (e.g., Cohen, Cohen, West & Aiken, 2003). They include concerns relating to the number of items included in self-report measures and the scales upon which items are scored. For example, some are advocates of traditional 11-point Likert scales (e.g., Krane, 1994), while others adopt a more creative approach when designing scales and allocating anchor terms (e.g., Zijlstra, 1993). In an attempt to reduce some of the concerns relating to the measurement of psychological constructs, the experiments reported in this thesis generally adopted measures that had been shown to have good reliability and had been used previously in competitive settings (e.g., the Competitive State Anxiety Inventory, the Mental Readiness Form, the Intrinsic Motivation Inventory). However, this approach meant that anxiety, effort and enjoyment were measured by assessing a different number of items (e.g., 7 for enjoyment, 1 for effort), and were scored on different scales (e.g., 1-7 for enjoyment, 0-150 for effort). As a consequence, these variables would have added differing amounts of error variance associated with the way in which they were scored, when included in mediation models. It is possible that such measurement differences could have made variables measured with more precision (e.g., enjoyment) more likely than others to elicit mediation effects. To control for this potential statistical confound, future studies could adopt equality, in terms of the number of items and the scale, across self-report measures.

Finally, it is conceded that the mediation analyses conducted in this thesis only tested for “statistical mediation”. While these analyses do provide insight into the roles that variables play in influencing performance, manipulations of these variables (e.g., enjoyment and effort) would provide stronger tests of causality. For example, if increased enjoyment is a true cause of improved performance, variations in performance should be evident in experiments that directly manipulate the levels of enjoyment experienced within a performance climate. Now that some statistical mediators of performance have been identified, these future studies can be undertaken.

Directions for Future Research

Some suggestions for future research activities have already been presented in the individual experimental chapters and in the preceding discussion. The purpose of this section is to present a brief overview of some key research themes that seem worthy of pursuing. Specifically, the results of the experiments presented in this thesis could be built upon by future research in the following areas: a) experimental research to provide more specific tests of the mechanisms suggested within processing efficiency theory and an enjoyment model; b) experimental research to develop a new integrative theory of the effects of competition on performance; c) applied research to examine interventions to promote optimal and robust performance during competitive pressure. Suggestions for research in each of these areas are now considered.

a) Experimental research to provide more specific tests of the mechanisms suggested within processing efficiency theory and an enjoyment-based model.

Although the current results establish that effort and enjoyment can facilitate performance during competition, it was not possible to ascertain why these variables have a facilitative effect. To examine why enjoyment had a facilitative effect on performance, research could manipulate enjoyment levels, and incorporate measures of resilience (cf. Fredrickson, 2004) in an attempt to place an enjoyment-based model within a more established theoretical framework (e.g., the broaden-and-build theory).

Processing efficiency theory suggests why effort should have a facilitative effect on performance. Specifically, increased effort should enhance performance because it results in additional processing resources being devoted to a task (Eysenck & Calvo, 1992). However future research is required to assess attentional resources and processing capacity in order to examine this suggestion. Such assessments could be made indirectly, through the incorporation of dual task conditions or attentional probing techniques (e.g., Gray, 2004).

Alternatively, peripheral psychophysiological indices of attention, such as eye gaze behaviour, could be obtained (Wilson, 2008). Specifically, reductions in the duration of the quiet eye period, which refers to the final fixation of the eye prior to movement initiation (Vickers, 2007), can indicate a reduction in processing efficiency (e.g., Behan & Wilson, 2008; Wilson, Vine & Wood, 2009). Eye tracking could provide particularly useful measures of attention during motor tasks as mobile eye tracking systems are suitable for use during sporting tasks such as basketball shooting (e.g., Wilson et al., 2009) and penalty taking in soccer (e.g., Wilson, Wood & Vine, 2009).

Finally, more direct measures of working memory activity could be obtained from neurophysiological measures of cortical activity such as electroencephalographic activity (e.g., Hatfield, Haufler, Hung & Spalding, 2004) or functional magnetic resonance imaging (e.g., Gray, Burgess, Schaefer, Yarkoni, Larsen & Braver, 2005). It is acknowledged that such signals are difficult to record during motor tasks, due to the constraints of the necessary recording equipment. Moreover, cortical measures of attention can be confounded by movement artefacts during motor tasks. As such, although the use of these measures in research is increasing (e.g., Hatfield et al., 2004), the aforementioned shortcomings limit their utility at present. However, it is envisaged that with the continued advancement of experimental equipment, research may be able to overcome these difficulties and gain accurate central measures of cortical activity during motor performance in the future.

b) Experimental research to present a new integrative theory of the effects of competition on performance.

The findings reported in this thesis, and those reported by others (e.g., Masters & Maxwell, 2008; Tauer & Harackiewicz, 2004; Wilson, 2008) provide support for elements of all of the aforementioned theories. Accordingly, it would seem a logical progression for future research to endeavour to integrate theoretical perspectives. Such research efforts should yield a more comprehensive model of the mechanisms which underlie the effects of competition on performance. To present such a theory, it would be interesting to examine interrelationships between positive emotions and variables such as effort and conscious processing. For instance, it is possible that an increase in positive emotions coincides with a decrease in levels of conscious processing, which could account for any facilitative effects of competition on the motor performance of experts.

Moreover, it would also be interesting to examine the underlying factors that promote an increase in effort. The data presented in this thesis suggest that anxiety is not always responsible for mediating increased effort. Perhaps external rewards (i.e. extrinsic motivation) play a role in mediating increased effort (cf., Ryan & Deci, 2000). Future research which concurrently examines effort, emotions, and other motivational variables, is required to shed light on this issue. Based on the data available at present, an integrative theory should present enjoyment and to a lesser extent, effort, as key variables associated with improved performance during competition.

c) Applied research to examine interventions to promote optimal and robust performance during competitive pressure.

The key implications of the findings presented in this thesis are that effort and enjoyment are elicited during competition. Moreover, they are often responsible for superior performance during competitions. Thus, applied research could examine interventions designed to boost enjoyment and effort[2], and accordingly, performance during competitive sport. For instance, coaches might use team competitions within training as a means of boosting performance and the associated self-confidence (e.g., Vealey, 2001) ahead of an important match.

Alternatively, the present findings could be used to inform interventions in an educational setting. Specifically, group competitions could be incorporated in classroom activities in an attempt to facilitate the learning of pupils. The available data highlight the increase in positive emotion and improvement in performance that such an intervention could yield.

Finally, future research could incorporate advanced physiological measures as a means of expediting motor skill acquisition and producing performers who are robust to the potential disruptions to performance under competitive pressure. For instance, the results

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[2] Some caution is expressed in recommending increased effort. It seems that effort can be beneficial to experts (Chapter 3) and on simple endurance based tasks (Chapters 4 & 5). However, increased effort might not benefit novice performance of motor tasks (Chapter 2) (cf. Zajonc, 1965).

yielded in this thesis suggest that the psychological profile which underlies optimal performances includes high levels of enjoyment and effort (at least in experts and for simple tasks), coupled with a reduced level of conscious motor processing. Accordingly, biofeedback interventions could be applied to promote physiological activation patterns consistent with these variables as skills are acquired. Such interventions could include breathing techniques to regulate cardiovascular activity in a pattern consistent with a challenge appraisal and increased effort (e.g., Jones et al., 2009; Mulder, 1992). Moreover, they could include eye-gaze biofeedback to encourage longer quiet eye fixations, and accordingly, more efficient information processing (cf. Wilson, 2008). Finally, they could include neurophysiological biofeedback to encourage cortical activity in brain regions associated with automatic as opposed to conscious processing (e.g., Ashe, Lungu, Basford & Lu, 2006; Zhu, Maxwell, Hu, Zhang, Lam et al., 2010). Such research could transform the way motor skills are taught to future generations.

Conclusion

Despite our knowledge of the effects of competition on performance, little was known about the mechanisms which underlie the competition–performance relationship. Accordingly, this thesis set out to advance our knowledge of such mechanisms by examining psychological, physiological and kinematic variables as mediators of the effects of competition on performance. The results served to further demonstrate the effects of competition on performance, and highlighted enjoyment and effort as key factors which influence performance under competitive pressure. There remains scope for future research to iron out the creases in our knowledge of the competition–performance relationship. However, through the adoption of an interdisciplinary approach, and the application of statistical mediation analyses, it is hoped that the current thesis has gone some way to advancing our understanding of this complex social climate.

This thesis began with the words of Henry Clay. Whilst the findings that are reported cannot confirm his contention that competition is the strongest power to influence human behaviour, they clearly demonstrate that it exerts powerful effects on our thoughts and actions. In doing so, it is hoped that the results will allow more individuals to thrive upon, and less to wilt, during the competitions of the future.

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APPENDICES

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1. Supplementary Analyses

1A) Mediation Analysis (anxiety–effort) performed on data from Chapter 2

The original effect of competitive pressure on effort was large: $F(2, 52) = 87.91$, $p<.001$, $\eta_p^2 = .77$.

The effect of competitive pressure on effort when co-varying for the effect of competitive pressure on anxiety remained large: $F(2, 50) = 17.33$, $p<.001$, $\eta_p^2 = .41$. This indicates anxiety did not mediate the observed increase in effort.

1B) Mediation Analysis (anxiety–effort) performed on data from Chapter 3

The original effect of competitive pressure on effort was large: $F(2, 48) = 58.97$, $p<.001$, $\eta_p^2 = .71$.

The effect of competitive pressure on effort when co-varying for the effect of competitive pressure on anxiety remained large: $F(2, 46) = 53.23$, $p<.001$, $\eta_p^2 = .70$. This indicates anxiety did not mediate the observed increase in effort.

1C) Mediation Analysis (anxiety–effort) performed on data from Chapter 4 and Chapter 5

Conditions	Original difference in effort (0-150)	Test for mediation			Residual difference in effort after mediation (0-150)
		Variable	*B*	*t*	
Chapter 4					
Do your best - Competition	7.11				
		Anxiety	1.18	1.18	4.96*
Chapter 5					
Individual – one-on-one competition	14.05				
		Anxiety	4.25	2.69**	10.20**
Individual – 2 vs. 2 competition	17.88				
		Anxiety	4.33	2.68**	13.08***
Individual – 4 vs. 4 competition	18.48				
		Anxiety	7.36	1.65***	6.99

Note: *p <.05, **p ≤.01, ***p ≤.001.

1D) Moderation Analysis (anxiety–performance) performed on data from Chapter 5

Regression analyses revealed that anxiety did not moderate the difference in performance between the individual competition and the one-on-one competition, b = -1.97, t(61) = -1.01, p = .32, and between the individual competition and the 2 vs. 2 competition, b = -1.29, t(61) = -0.77, p = .45.

Anxiety did moderate the difference in performance between the individual competition and the 4 vs. 4 competition, b = -4.45, t(61) = -2.08, p <.05.

1E) Moderation Analysis (anxiety–performance) performed on data from Chapter 2

Regression analyses revealed that anxiety did not moderate the difference in number of putts holed between low pressure and medium pressure, $b = 0.00$, $t(51) = 0.07$, $p = .94$, and between low and high pressure, $b = 0.02$, $t(51) = 1.36$, $p = .18$.

1F) Moderation Analysis (anxiety–performance) performed on data from Chapter 3

Regression analyses revealed that anxiety did not moderate the difference in mean radial error between low pressure and medium pressure, $b = -0.17$, $t(47) = -1.55$, $p = .13$, and between low and high pressure, $b = -0.13$, $t(47) = 1.15$, $p = .26$.

1G) Mediation Analysis (anxiety–conscious processing) performed on data from Chapter 3

The original effect of competitive pressure on conscious processing was medium-to-large: $F(2, 48) = 7.95$, $p<.001$, $\eta_p^2= .25$.

The effect of competitive pressure on conscious processing when co-varying for the effect of competitive pressure on anxiety remained medium-to-large: $F(2, 46) = 4.88$, $p<.01$, $\eta_p^2 = .18$. This indicates anxiety did not mediate the observed increase in conscious processing.

2. Questionnaires

2A) Competitive State Anxiety Inventory 2-Revised

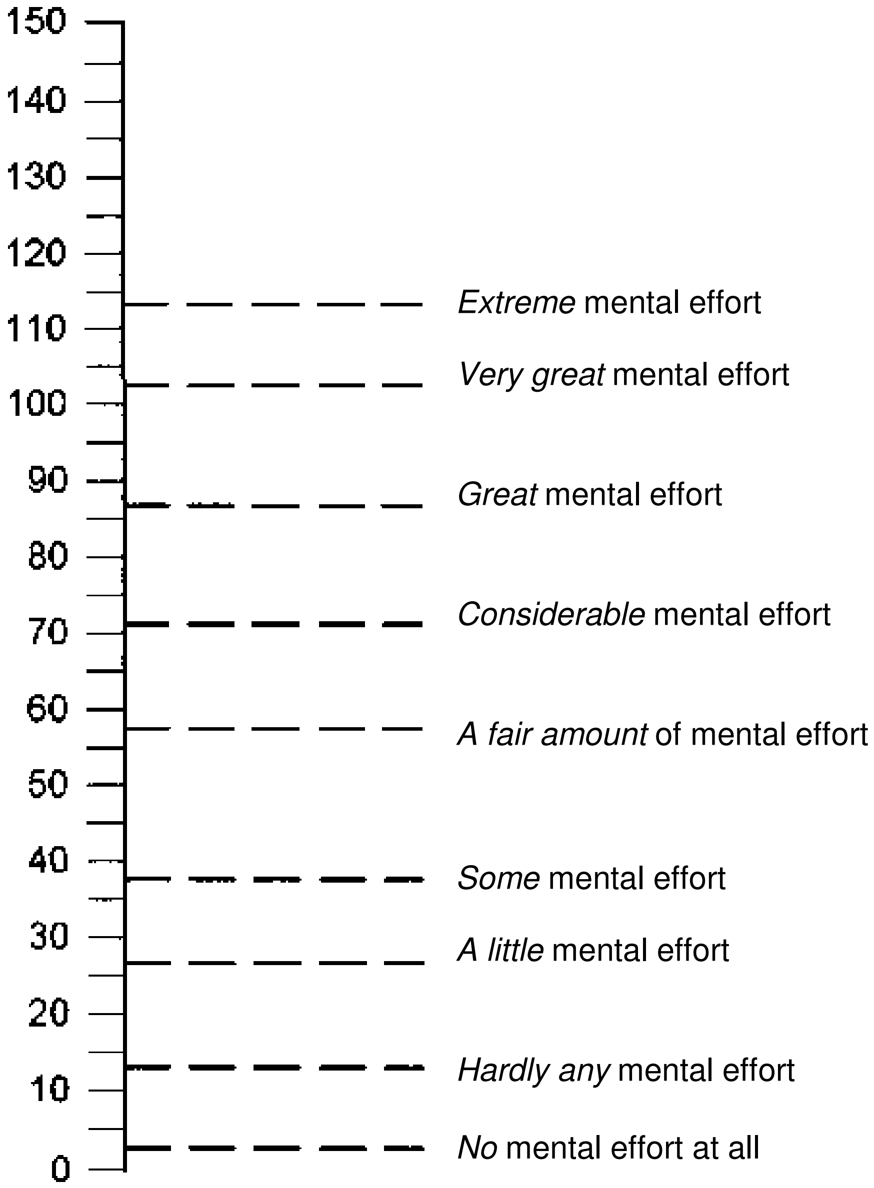
A number of statements that golfers have used to describe their feelings while putting are given below. Read each statement then circle the appropriate number to the right of the statement to indicate how **you felt** while putting in the **previous condition**:

WHILE PUTTING…	**Not at all**	**Somewhat**	**Moderately so**	**Very much so**
1. I felt jittery	1	2	3	4
2. I was concerned that I may not putt as well as I could	1	2	3	4
3. My body felt tense	1	2	3	4
4. I was concerned about missing putts	1	2	3	4
5. I felt tense in my stomach	1	2	3	4
6. I was concerned about choking under pressure	1	2	3	4
7. My heart was racing	1	2	3	4
8. I was concerned about performing poorly	1	2	3	4
9. I felt my stomach sinking	1	2	3	4
10. I was concerned that others would be disappointed with my performance	1	2	3	4
11. My hands were clammy	1	2	3	4
12. My body felt tight	1	2	3	4

2B) Rating Scale for Mental Effort

Mental effort is described by Zijlstra (1993) as the amount of mental resources (focus) that one applies to a task.

Please mark an **‘X’** on the scale to indicate your level of **mental effort** during **the previous 6 putts**. You will not be judged on the information that you give here. Please respond honestly.



2C) Pressure subscale of the Intrinsic Motivation Inventory

Please think about how you felt while performing the **previous 6 putts**, then read the following statements and circle the number that best reflects your feelings:

DURING THE PREVIOUS 6 PUTTS...	**Not at all true**			**Somewhat true**			**Very true**
I did not feel nervous	1	2	3	4	5	6	7
I felt very tense	1	2	3	4	5	6	7
I was very relaxed	1	2	3	4	5	6	7
I was anxious	1	2	3	4	5	6	7
I felt pressured	1	2	3	4	5	6	7

2D) Adapted version of the conscious motor processing subscale of the Movement Specific Reinvestment Scale

Please think about how you felt while performing the **previous 6 putts**, then read the following statements and circle the number that best reflects your feelings:

WHILE PUTTING…	**Never**		**Sometimes**		**Always**
I thought about my stroke	1	2	3	4	5
I reflected about my technique	1	2	3	4	5
I tried to figure out why I missed putts	1	2	3	4	5
I was aware of the way my body was working	1	2	3	4	5
I thought about bad putts	1	2	3	4	5
I was conscious of my movements	1	2	3	4	5

2E) Mental Readiness Form-Likert

Please circle the number that best describes your thoughts during the previous task.

During the **previous** task, my **thoughts** were…										
CALM										**WORRIED**
1	2	3	4	5	6	7	8	9	10	11

2F) Enjoyment subscale of the Intrinsic Motivation Inventory

Please indicate what you thought about the **previous** task.

The **previous** task ...	**Not At All True**			**Somewhat True**			**Very True**
I enjoyed it very much	1	2	3	4	5	6	7
It was fun to do	1	2	3	4	5	6	7
I thought it was boring	1	2	3	4	5	6	7
It did not hold my attention at all	1	2	3	4	5	6	7
I would describe it as very interesting	1	2	3	4	5	6	7
I thought it was quite enjoyable	1	2	3	4	5	6	7
While doing it, I was thinking about how much I enjoyed it	1	2	3	4	5	6	7