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A multidisciplinary approach to examine mental toughness

Alzahrani, Turki

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A multidisciplinary approach to examine mental toughness

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Turki Alzahrani

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Thesis Summary

This thesis investigates the relationship of both trait and state explanations of Mental Toughness (MT) upon a range of behavioural and psychophysiological outcome variables that should relate to the construct of MT (e.g., performance, heart rate, muscle activity, kinematic movement, and cortisol).

Chapter 1 presents a holistic overview of the strengths and limitations of research in MT and offers some novel approaches that could advance knowledge in this area. The introduction briefly explains different concepts that relate to the construct of MT. The strengths and limitations of trait (personality) and state (self-report) perspectives of MT are reviewed. Finally, future outcome variables that should be theoretically related to MT that have yet to be fully explored are discussed. This discussion sets out in detail, the purpose of the thesis.

Chapter 2 aimed to advance previous research findings where personality traits (i.e., low reward and high punishment sensitivities) have been shown to predict Mentally Tough behaviour (MTb) and performance outcomes under pressure (e.g., Beattie, Alqallaf, & Hardy, 2017; Hardy, Bell, & Beattie, 2014). As suggested in the research overview from Chapter 1, these individuals may demonstrate unique psychophysiological response to stress that allow them to tolerate higher levels of pressure than their less mentally tough counterparts. Therefore, we hypothesized that individuals high in punishment and low in reward sensitivities (and those high in self-report MT) would show little or no increase in heart rate, and show stable muscle activity and movement kinematics from low-stress to high-stress conditions, compared to less mentally tough individuals. The stress condition involved participants making a single putt where they could double or lose all the money they had earned up to that point. Results indicated that, when reward sensitivity was low and punishment sensitivity increased, heart rate reactivity was blunted and movement kinematics

(club-head angle) were more consistent when transitioning from a low to high stress environment. However, no significant relationships were found between self-report levels of MT, psychophysiological and movement kinematic measures.

Chapter 3 addressed some of the limitations from Chapter 2. Specifically, the stress manipulation was modified to provide participants with early warning of the stressor, and, therefore, more time to prepare. The stress manipulation was also intensified by removing money from participants for missed putts, and adding peer pressure by having participants complete the experiment in pairs. We also extended the psychophysiological approach from Chapter 2 by examining cortisol. Results regarding personality and heart rate differed slightly from Chapter 2. Importantly, with early warning of the stressor, personality no longer predicted heart rate reactivity, but it did predict preparatory heart rate deceleration, an index of motor preparation. Preparatory heart rate deceleration was disrupted on transition from low-stress to high-stress conditions, but when reward sensitivity was low, increasing punishment sensitivity was associated with more consistent deceleration across both low-stress and high-stress conditions. Moreover, when reward sensitivity was low, increasing punishment sensitivity was associated with less angular error (better performance). Finally, contrary to our hypothesis, cortisol increased from the high stress condition to the low stress condition.

Chapter 4 draws upon studies of early versus late preparation, and prevention versus promotion focus, to account for the subtly different results across Chapter 2 and Chapter 3. In doing so, it discusses the theoretical and applied implications of the thesis. Limitations and strengths of the thesis are discussed and future research directions are proposed.

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Chapter 1

General Introduction

Mental Toughness Introduction

Mental toughness is a term commonly used in sport to explain why some athletes excel under difficult circumstances and others fall by the wayside. Mental toughness has been described as a "desirable skill allowing athletes to utilize a range of cognitive, emotional, and behavioural resources to maintain (or even improve) performance standards under pressure" (Beattie, Alqallaf, Hardy, & Ntoumanis, 2018, p. 1). However, due to different perspectives of the definition of mental toughness, conceptually speaking it is poorly understood (Bull, Shambrook, James, & Brooks, 2005; Clough, Earle, & Sewell, 2002; Connaughton, Hanton, & Jones, 2010; Connaughton, Wadey, Hanton, & Jones, 2008; Driska, Kamphoff, & Armentrout, 2012; Jones, Hanton, & Connaughton, 2002; Thelwell, Weston, & Greenlees, 2005).

Mental Toughness Definition

One of the main challenges in research regarding mental toughness is that there has yet to be a consensus on what it is. For example, research (so far) has produced eight definitions of mental toughness (see Gucciardi, 2017). One of the earlier definitions of mental toughness came from the work of Jones et al. (2002). Jones at al. (2002) described mental toughness as "having the natural or developed edge that enables you to: (i) generally, cope better than your opponents with the many demands (competition, training, lifestyle) that sport places on a performer; (ii) specifically, being more consistent and better than your opponents in remaining determined, focused, confident, and in control under pressure" (p. 209). Yet others (e.g., Clough et al., 2002) have defined mental toughness as individuals who "tend to be sociable and outgoing; as they're able to remain calm and relaxed, they are competitive in many situations and have lower anxiety levels than others. With a high sense of self-belief and an unshakeable faith that they can control their own destiny, these individuals can remain relatively unaffected by competition or adversity" (p.38). The first definition uses significant others as a reference point for being mentally tough and the second uses the self as a reference point for being mentally tough. More recent definitions of mental toughness seem to define it on a more global scale with specific reference to goal achievement under pressure. For example, Hardy, Bell, and Beattie (2014) defined mental toughness as “the ability to achieve personal goals in the face of pressure from a wide range of different stressors” (p. 70). In a similar fashion Gucciardi (2017) defines mental toughness as “a state-like psychological resource that is purposeful, flexible, and efficient in nature for the enactment and maintenance of goal directed pursuits” (p. 18). Critics of mental toughness research also argue that definitions may be helpful in developing our understanding to what the mentally tough athlete can do but limits our understanding into what mental toughness is (Crust, 2007).

Self-report Mental Toughness Questionnaires

Just as there are several definitions of mental toughness (Gucciardi, 2017), research has also provided numerous amounts of quantitative assessment to measure it (only a few of the more prominent assessments are discussed here). One of the earlier assessments of mental toughness, the Psychological Performance Inventory (PPI) (Loehr, 1986) consists of 42-item that measures mental toughness via seven subscales of Self-confidence (i.e., believing in your abilities), Negative Energy (i.e., perceiving threatening or frustrating problems as challenges within your control), Attention Control (i.e., sustaining an optimal level of focus whereby one blocks out irrelevant thoughts while attending to task-relevant information), Visualisation and Imagery Control (i.e., controlling one's mental images in a positive and constructive manner), Motivation (i.e., maintaining high levels of motivation), Positive Energy (i.e., using energy sources such as joy and grit to control and maintain the flow of positive energy), and Attitude Control (i.e., having an attitudinal approach characteristic of elite performers). Each subscale contains six items, each scored on a 5-point Likert scale, with scores for each subscale ranging from 6 to 30.

In a refinement of the PPI Golby, Sheard, and Wersch (2007) developed the Psychological Performance Inventory Alternative (PPIa). The PPIa contains 14-items that measures mental toughness via four subscales (e.g., Determination, Self-belief, Positive Cognition, and Visualization). Sample items include, "The goals I've set for myself as a player keep me working hard" (Determination); "I lose my confidence very quickly" (Self-belief); and "I can change negative moods into positive ones by controlling my thinking" (Positive Cognition); and "I mentally practice my physical skills" (Visualization).

The Mental Toughness Questionnaire-48 (MTQ-48; Clough et al., 2002) contains 48-items across four subscales (e.g., Challenge, Commitment, Control, and Confidence) each containing 12 items. The MTQ-48 uses a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Sample items include, "Challenge usually brings out the best in me" (Challenge); "I usually find something to motivate me" (Commitment); "I generally hide my emotion from others" (Control); and "I usually speak my mind when I have something to say" (Confidence). The MTQ-48 can further be split into 8 separate subscales termed; Life Control, Emotional Control, Goal Orientation, Achievement Orientation, Risk Orientation, Learning Orientation, Confidence in Abilities, and Interpersonal Confidence. There are some concerns about the MTQ-48 in that three of the subscales (Challenge, Commitment, and Control) are based on hardiness theory (Maddi, 2004), which could suggest that the MTQ-48 is simply hardiness repackaged. Secondly, statistical procedures for the MTQ-48 are not clearly reported (Crust, 2007) and have come under recent scrutiny (Gucciardi, 2012).

The Sport Mental Toughness Questionnaire (SMTQ) (Sheard et al., 2009) contains 14-items that measures mental toughness as a multidimensional concept via three subscales (i.e., confidence, constancy, and control). The SMTQ uses a Likert scale from 1 (not at all true) to 4 (very true). Sample items include, "I have unshakeable confidence in my ability" (confidence); “I worry about performing poorly” (Control); “I am committed to completing the tasks I have to do” (Constancy).

Researchers have also designed sport specific assessments of mental toughness that aim to capture content specific aspects of mental toughness within a sport. For example, Gucciardi, Gordon, and Dimmock (2009b) developed the Australian Rules football Mental Toughness Inventory (AfMTI) which contains 24-items that assess four context-specific components of mental toughness in Australia Rules football e.g. thrive through challenge (e.g., ‘‘I am able to persist through any adversity that I face’’), sport awareness (e.g., ‘‘I am aware of the roles and responsibilities of my teammates’’), tough attitude (e.g., ‘‘Physical fatigue does not affect my performance’’), and desire success (e.g., ‘‘Being part of a successful team is important to me’’). Gucciardi and Gordon (2009) also developed the Cricket Mental Toughness Inventory (CMTI) which contains 15-items that measure mental toughness via five subscales: affective intelligence (i.e., ability to regulate emotions to facilitate performance), attentional control (i.e., regulate focus and concentration to facilitate performance), resilience (i.e., ability to bounce back from and/or experience positive outcomes following exposure to a significant adversity or challenge), self-belief (i.e., belief in your physical ability to perform to your potential), and desire to achieve (i.e., desiring and remaining committed to constant performance improvements).

Limitations of Self-report Mental Toughness

One criticism relating to the above section is that in this relatively small selection of mental toughness questionnaires, they contain over 30 factors. In relation to this, another criticism in the literature is that (nearly) everything that has to do with positive psychology has been associated with mental toughness. For example, Anderson (2011) makes a comprehensive list of over 100 characteristics that have been associated with quantitative and qualitative approaches to mental toughness. Some of these include being focused, having competence, having the ability to keep going, being optimistic, having the ability to withstand pain, having endurance and hardiness, blocking negative thoughts, ignoring other people, having self-efficacy and self-esteem, making positive adjustments, being adventurous, coping better than an opponent, having game intelligence, being able to deal with setbacks, having self-belief, setting goals, having influential parents, managing time, controlling the environment, having insatiable desires, having the desire to win and the desire to achieve, positive adaption, self-motivated, self-confident, recovery rates from injury, vision, overcoming adversity, having the ability to bounce back and handle failure as well as success (Anderson, 2011).

Unidimensional and multidimensional assessments

A further confound in quantitative assessment of mental toughness is that they are either viewed as a unidimensional concept (Gucciardi, Hanton, Gordon, Mallett, & Temby 2015) or a multidimensional concept (e.g., Clough et al., 2002; Sheard et al., 2009). For example, in conceptualising their assessment of mental toughness, Gucciardi et al. (2015) found considerable empirical overlap existed between factors labelled self-belief, attention regulation, emotional regulation, success mind-set, context knowledge, buoyancy, and optimism. Therefore, these authors argued that mental toughness may best be explained as a unidimensional concept. Their measure termed the Mental Toughness Index (MTI) contains eight-item that measures mental toughness as a unidimensional concept. The original measure was developed as a 7-facot measure containing self-belief, attention regulation, emotion regulation, success mind-set, context knowledge, buoyancy, and optimism. However, due to significant conceptual overlap, Gucciardi et al. (2015) refined a single factor measure. Sample items include “I believe in my ability to achieve my goals”, “I strive for continued success” and “I can find a positive in most situations”.

State Perspectives of Mental Toughness

Some research findings refer to mental toughness as a state like variable that is situational dependant that can change across time. For example, in their interview of 12 elite tennis players on their perceptions of mental toughness, Weinberg, Butt, Mellano, and Harmison (2017) found that athletes reported feeling more mentally tough in some situations than others, suggesting mental toughness is a state like component. Furthermore, in their development of an 8-item assessment of mental toughness Gucciardi et al. (2015) repeatedly assessed mental toughness in a sample of undergraduate students over a ten-week period. They found that 56% of the variance in mental toughness could be explained as a state-like concept, further supporting Weinberg et al. (2017). However, this also indicates that 44% (nearly half of the sample), reported mental toughness as a trait-like construct that remained stable across time.

Developing Mental Toughness

In understanding how best to intervene on athletes' levels of mental toughness, there is a wealth of qualitative studies that can guide best practice. For example, Thelwell et al. (2005) reported that some elite soccer players mentioned that different environments and experiences during their formative years contributed to the development of mental toughness. That is, mental toughness can be developed from the early stages (at a young age) of training and help the athlete when they are in more difficult performance environments and more challenging training at later stages.

The training environment has also been shown to influence the athlete's development of mental toughness. For example, Thelwell, Such, Weston, Such, and Greenless (2010) reported that simulating competition, competition preparation, overcoming problems, recovering and training with injury, and learning new moves or complex skills provide athletes with the knowledge that encourages the development of mental toughness. Also, Bull et al. (2005) reported that exposure to foreign cricket and opportunities to overcome early setbacks provide the athlete with opportunities where they can develop mental toughness. In addition, Gucciardi, Gordon, Dimmock, and Mallett (2009) reported that elite cricket coaches who provided their athletes with competition simulation, used challenging training environments, and encouraged enjoyment and skill improvement over winning, furthered their athletes' mental toughness development. Finally, Connaughton et al. (2008) reported that environmental factors such as coaches' leadership, vicarious experience, skill mastery, critical incidents, and social support are responsible for an athlete's mental toughness development.

To summarize, research indicates that early experiences of adversity that are carefully managed in the training environment, leads to the development of mental toughness. Recent research has also highlighted the importance that self-regulated training behaviours has upon mental toughness. For example, Beattie et al. (2018) hypothesised that self-regulated training behaviours would mediate the relationship between self-report mental toughness and coach rated perceptions of how well the athlete performs under pressure (i.e., mentally tough behaviour). They examined self-report mental toughness (athletes view), training behaviours (athlete and coach rated) and informant ratings of (mentally tough behaviour; coach rated). They found that self-regulated training behaviours (coach and athlete rated) had positive relationships with athlete self-reports of mental toughness and coach ratings of mentally tough behaviour. Further, they found that there was a direct and positive relationship between self-report mental toughness and coach ratings of mentally tough behaviour. Finally, training behaviours (as assessed by both the coach and the athlete) had a significant indirect relationship between mental toughness and mentally tough behaviour. Therefore, the relationship between self-report mental toughness and coach's perception of the athlete's mentally tough behaviour could be partially explained by how well the athlete trained.

Mental Toughness Interventions

Despite the abundance of qualitative research findings relating to the development of mental toughness it seems strange that there are a limited number of mental toughness interventions. This could be attributed to the difficulty of distinguishing between mental toughness intervention and psychological skill training (Bell, Hardy & Beattie, 2013; Gucciardi et al., 2009). For example, Gucciardi et al. (2009) found no differences in self, parent, and coach ratings of mental toughness between a psychological skills training intervention and a mental toughness intervention. Bell et al. (2013) used an adversity-based approach (punishment) where athletes had to clean the changing rooms or miss the next training session if they did not achieve the performance standards expected of them. According to Bell et al. (2013) experiencing and overcoming punishment-conditioned stimuli in a training environment should systematically desensitise the individual to stress and anxiety associated with threat detection (Wolpe, 1958). Further, being repeatedly exposed to punishment conditioned stimuli could also sensitize athletes to such stimuli giving them the maximum opportunity to pick threat up early and deal with it. To avoid any negative harmful effects of punishment, the intervention was delivered in transformational manner where all participants (including coach related staff) were punished for their mistakes. Second, to help athletes deal with their mistakes, they were provided with a tailored psychological skills training intervention. Over a 2-year period, in comparison to the control group, the intervention group demonstrated significant improvements in coach-rated mentally tough behaviour, objectively assessed competitive performance statistics, indoor batting against pace, and a multistage fitness test.

Mental Toughness and Performance

Research has shown some correlational findings to support a positive relationship between mental toughness and performance. However, some of these findings seem tentative to say the least. For example, Crust and Clough (2005) found a positive relationship between mental toughness and physical endurance in that, higher levels of mental toughness led to longer times of holding a weight at arm's length. Furthermore, Gucciardi et al. (2015) examined the relationship between mental toughness and performance in the workplace as well as a military environment. In the work place, their 8-item unidimensional Mental Toughness Index significantly predicted supervisors rated performance (e.g., "Adequately completes assigned duties" and "Fulfils responsibilities specific in job description"). In the military environment, the participants completed a 6-week selection test for entry into a Special Forces unit. The selection test consisted of a 6-week course specifically designed to examine each candidate's suitability for entry into elite military training. The Mental Toughness Index was used to measure mental toughness, and performance was coded as a dichotomous variable where failure = 0 and pass = 1. The results revealed that mental toughness was positively associated with the military selection test (even when controlling for hardiness and self-efficacy).

Mentally Tough Behaviour:

Further issues concerning self-report assessments of mental toughness is that they are open to social desirability and self-presentation abuse (Hardy et al., 2014). Further, according to Hardy et al. (2014), the general overuse of examining elite level athletes in qualitative research also confuses talent, practice, skill level, and other variables that are associated with good performance. Hardy et al. (2014) also noted that there is little point in linking cognitions, attitudes and emotions to mental toughness unless one knows that mentally tough behaviour has occurred (see also Arthur, Fitzwater, Hardy, Beattie, & Bell, 2015). Therefore, recent research in mental toughness has moved away from relying upon self-report mental toughness questionnaires and has instead focussed upon observational behavioural assessments. For example, researchers argue that a more reliable method of assessing mental toughness is to gather informant ratings of behaviours concerning the individual involved, (Andersen, McCullagh, & Wilson, 2007; Beattie et al., 2017, 2018; Gucciardi et al., 2015; Hardy et al., 2014). In other words, if athletes espouse to be mentally tough, then they should display some level of mentally tough behaviour (e.g., coach ratings of their athletes' performance under pressure). Mentally tough behaviour has recently been defined as "a purposeful yet adaptable verbal or physical act that contributes positively to performance through the attainment and progression of self-referenced objectives and goals" (Anthony, Gordon, Gucciardi, & Dawson, 2017) (p.5).

With reference to observational behavioural assessments of mental toughness, Hardy et al. (2014) created an 8-item informant questionnaire assessing mentally tough behaviour in cricket. This questionnaire relies on coaches rating how well their athletes perform under challenging or difficult circumstances (e.g., "When people are relying on him to perform well"; "When he has to perform at a high level all day"; and "When his preparation has not gone to plan"). The 8-item informant uses a Likert scale from 1 (rarely) to 7 (regularly) with a midpoint anchor of 4 (sometimes). By assessing behaviour, it is at least possible to test the direct relationship between self-report assessments of mental toughness against reliable informant data.

Others have espoused to examine agreement or disagreement in perceptions of mental toughness between coaches and athletes. For example, Cowden, Anshel, and Fuller (2014) examined the difference between self-report and coach ratings of mental toughness in sixteen elite tennis players using the Sports Mental Toughness Questionnaire (Sheard et al., 2009). Their findings showed a high level of disagreement in perceived ratings in that athletes reported higher levels of self-report mental toughness than their coaches reported for their athletes. Further, there was no significant correlation between self-report levels of mental toughness and coach ratings of mental toughness. One of the issues in this type of research is that it is impossible for the coach to be aware of the athlete's innermost thoughts and perceptions of mental toughness. However, these findings further highlight the issue that athletes may be positively biased towards self-reporting their own perceptions of mental toughness.

Hardy et al. (2014) are not the only researchers that use informant ratings to measure mental toughness behaviour. For example, Diment (2014) created a 15-item instrument that tested mental toughness behaviour through informant ratings. Both male female Danish soccer players aged under-18 participated in the study. Coaches rated their players' mentally tough behaviour during competition. The results showed high reliability and validity to measure mental toughness as a behaviour. Additionally, Arthur et al. (2015) also used a behavioural approach to examine mental toughness of army recruits trying out for P-Company (British Parachute Regiment). Arthur et al. (2015) designed and tested 6-items that were rated by section commanders to measure mentally tough behaviour. The six items focused on the military training environment e.g., "The conditions are difficult on exercise" and "He has been reprimanded/punished". Findings revealed that their behavioural assessment of mentally tough behaviour significantly predicted selection (over and above that of fitness levels).

Furthermore, Beattie, Alqallaf, and Hardy (2017) used a similar approach to examine mental toughness behaviour. They asked coaches to rate their swimmers mentally tough behaviour using a Swimming Mental Toughness Inventory (SMTI). The Swimming Mental Toughness Inventory (SMTI) is 15-item scale used by coaches to rate swimmers' mentally tough behaviour. Items included "Going into the race the competition is particularly tight" and "S/he is swimming up an age group and/or against a national squad member". However, Beattie et al. (2017) found that, after controlling for athlete age and coach experience, no significant correlation was found between mentally tough behaviour and swimming performance (r = -.067, p = .57).

Personality and Trait Perspectives of Mental Toughness

Early research in personality highlighted tough mindedness as one of sixteen traits that described personality (Cattell, 1957). Individuals who are tough minded tend to be realistic, down-to-earth, independent, responsible, self-reliant, often unmoved, hard, cynical, and smug (Kobasa, 1979). In contrast, tender-minded individuals are fussy, dependant, emotionally sensitive, day-dreaming, and temperamental. Hardiness is a term derived from the field of health psychology (Kabasa 1979; Kabasa, Maddi, & Khan, 1982) and comprises of three interrelated concepts of control, challenge, and commitment. Control refers to an individual feeling and acting that they are influencing their surrounding events by their own efforts. Challenge refers to dispositional beliefs that change (rather than stability) is normal. For example, such individuals see change as an opportunity for learning and growth rather than a threat. Finally, commitment refers to one's tendency to be involved in life activities and respond with genuine curiosity where such people immerse themselves in their own activities (Clough & Strycharczyk, 2012). Hardiness is the mechanism that acts as a buffering effect for people during stressful events (Kobasa et al., 1982). Early research in hardiness found that under stress, executives who reported higher levels of hardiness remained healthier than executives who were less hardy (Kobasa et al., 1982). Support for the importance of hardiness in sport comes from a study by Golby, Sheard, and Lavallee (2003), in which 70 international rugby league players were assessed for mental toughness and hardiness by standard measures (the Psychological Performance Inventory (Loehr,1986) and the Personal Views Survey (Maddi & Khoshaba, 2001), respectively). Hardiness emerged as a significant factor affecting performance.

The revised Reinforcement Sensitivity Theory (rRST)

Other researchers have also suggested that mental toughness could be explained via trait like behaviors. For example, Hardy et al. (2014) suggested that if mental toughness and mentally tough behavior is a relatively stable disposition that it is unlikely to change quickly over time, it could be explained by relevant personality theories. One personality theory that Hardy et al. (2014) hypothesized could explain mentally tough behavior was Gray and McNaughton's (2000) revised Reinforcement Sensitivity Theory (rRST). According to Gray and McNaughton (2000) there are three neuropsychological systems underpinning rRST. These neural systems mediate responses to reward, punishment and goal conflict. For example, rewarding appetitive stimuli (e.g., money or food) activates the behavioural approach system (BAS) where the individual approaches such rewarding stimuli. Second, the fight, flight, freeze system (FFFS) is activated when specific threats are detected (e.g., job interviews, dental appointments, or viva examination). Here, avoidance or carful approach to such threatening stimuli is paramount. The final system termed behavioural inhibition system (BIS) is associated with resolving approach-avoidance conflict between the BAS and FFFS. For example, one may avoid threat in the hope that it may subside. However, if threat becomes unavoidable, then the BIS system will resolve such approach-avoidance conflict by engaging with appetitive stimuli due to the reward that may be inherent (prospects of a good job), despite the impending (punishment) consequences (social threat of failing an interview). As discussed above, Hardy et al. (2014) hypothesised that rRST could explain mentally tough behaviour. They noted several studies where reward sensitivity was associated with high levels of performance and mild reactions to stress under threatening conditions (e.g., Perkins & Corr, 2006; Perking, Kemp, & Corr, 2007). Further, individuals high in punishment sensitivity seem to suffer from poor performance under pressure (Perkins et al., 2007), avoid threatening situations (Perkins & Corr, 2006), and negatively evaluate their capacity to deal with pain (Muris et al., 2007). Based on those findings, Hardy et al. proposed that higher levels of reward sensitivity would be associated with higher levels of mentally tough behaviour, whereas higher levels of punishment sensitivity would be associated with lower levels of mentally tough behaviour. One final point regarding Hardy et al.'s hypothesis is that, even though reward and punishment sensitivities are orthogonal constructs (Gray & McNaughton, 2000), studies testing interactive effects between these two systems are rare. Therefore, Hardy et al. predicted that mentally tough behaviour would be associated with high levels of reward and low levels of punishment sensitivity. However, results revealed findings contrary to their hypothesis. Specifically, across two separate studies of elite level county cricketers, a significant interaction between reward and punishment sensitivity revealed that when reward sensitivity was low, increasing levels of punishment sensitivity were associated with an increase of mentally tough behaviour. Further, when reward sensitivity was high, as punishment sensitivity increased, mentally tough behaviour decreased. To clarify these findings, Hardy et al. conducted a follow up study and found that participants who were high in punishment and low in reward sensitivity detected threats early thereby enabling them more time to plan an effective response.

There are some limitations to the work of Hardy et al. (2014). For example, across studies, their sample was restricted to male elite cricketers aged 16-18. Therefore, Beattie et al. (2017) followed on from this line of research and examined the interaction between punishment and reward sensitivities on mentally tough behaviour in a sample of male and female swimmers with a much wider age range and experience. These authors found that when reward sensitivity was low, as punishment increases mentally tough behaviour increased. Furthermore, when reward sensitivity was low, as punishment increases race time for swimmers increased. Thereby showing support for Hardy et al.'s (2014) initial findings.

To further explore these findings, Manley, Beattie, Roberts, Lawrence, and Hardy (2017) explored the possibility that individuals high in punishment sensitivity are able to prosper from being sensitive to threat. However, Hardy et al. also proposed that this would only be the case if the punishment sensitive individual already had a set of well learned coping strategies and that threat was detected sufficiently early enough for coping strategies to take effect. In their two-study approach Manley et al. used a precision hand-grip task. In study 1, all participants were trained in the use of coping strategies (imagery, muscle relaxation, and cue words). In study 2 they were not. Participants in both studies were randomly put into early or late threat warning conditions. In the early warning condition participants were told at the start of testing exactly what the stress manipulation would be. In the late warning condition, participants were only told of the stress manipulation immediately before it took part. In study 1, results revealed that punishment sensitivity positively related to performance in the stress condition when early threat warning was given. However, punishment sensitivity negatively related to performance in the stress condition when late threat warning was given. This was despite all participants being trained in the use of coping strategies. Results in study 2 mirrored that of study 1 despite no coping strategies being taught to the participants. However, across both studies the beneficial use of coping strategies was assessed. Even though in study 2 none were taught, participants reported using their own set of coping strategies which enabled them to better deal with the competition but only if they were given enough warning (i.e., early threat warning). Therefore, it seems that individuals who are punishment sensitive have a set of cognitive strategies (innate or taught) which help them to better deal with early threat detections (Hardy et al., 2014).

With regards to research in personality and mental toughness, it appears that strong links exist between the personality traits of punishment and reward sensitivity on mentally tough behaviour and performance (e.g., Beattie et al., 2017; Hardy et al., 2014; Manley et al., 2017). It also stands to reason that athletes who display high levels of mentally tough behaviour may be doing so because at a psychophysiological level, they are remaining relatively calm and relaxed. If this is indeed the case, then a much more detailed understanding of the psychophysiological markers that underpin such relationships would significantly advance research in this area (Hardy et al. 2014).

Psychophysiology of mentally tough behaviour

The sections reviewed above indicate a number of limitations in quantitative and qualitative approaches to assessing mental toughness. Moreover, they indicate that personality-based approaches grounded in established psychological theory (e.g., rRST) show greater promise and possess better predictive utility (e.g., Hardy et al., 2014). Using personality and rRST to theorize about MT behavior has the additional advantage of permitting the formation of psychophysiological predictions – based on stress reactivity and motor preparation research – which could shed light on the mechanisms that underpin MT. Understanding the psychophysiological associates of MT behavior is desirable because it could pave the way for biofeedback interventions that encourage the physiological responses that are compatible with MT behaviors. Coverage of candidate psychophysiological variables that could be used to index awareness of threat and preparation for action, the key processes that Hardy et al. (2014) link to MT behavior, is provided next.

Stress reactivity. Reactivity to stress refers to changes in physiological reactions (e.g., an increase in heart rate) from low-stress to high-stress environments. Physiological stress reactivity is evident in several systems such as the autonomic nervous system (e.g., cardiovascular reactions), the neuromuscular system (e.g., muscular reactions) and the neuroendocrine system (e.g., hormonal reactions). For example, a typical response to stress would involve activation of the hypothalamus-pituitary-adrenal axis, where the hypothalamus stimulates the pituitary which, in turn, prompts the release of cortisol via the adrenal cortex (Foley & Kirschbaum, 2010). At the same time, the posterior hypothalamus usually activates the sympathetic nervous system via innervation of the adrenal medulla, prompting the release of adrenaline and an increase in heart rate (Obrist, 1981). Such hormonal and sympathetic activation can also activate the neuromuscular system, such as increasing muscular activation as the organism prepares for flight or to fight (e.g., Weinberg & Hunt, 1976).

Psychophysiological indices of stress reactivity are of interest from the perspective of MT because MT behavior is thought to be underpinned in part by superior awareness of and preparedness for dealing with upcoming stressors (Hardy et al., 2014). There has already been research evidence showing effects of stressor awareness of and preparedness on physiological reactivity. For example, Martins, McIntyre and Ring (2015) examined the effect of the electric shock via five intensities from nonpainful stimuli to extremely painful stimuli in two groups of healthy individuals (predictable and unpredictable). They found that participants who were aware of the intensity of the upcoming stressor (predictable) displayed less heart rate reactivity than those participants who were not aware of the intensity of the upcoming stressor (unpredictable). Similarly, Wallace (1984) conducted an experiment to examine stress reactivity preceding a minor gynaecological operation. Eighty patients were allocated to either a routine care (control) group, routine care plus minimally informative preparation booklet, or a routine care plus maximally informative preparation booklet. Results revealed that patients in the maximally informative preparation group displayed lower pre-operative heart rate and blood pressure, indicating reduced stress reactivity, compared to the other two groups.

Similar effects have also been reported with other psychophysiological measures of stress reactivity. For example, Hejazi and Hosseini (2012) examined the effects of a dedicated preparation phase preceding a competition on the cortisol levels of professional elite male runners. They found that cortisol levels decreased from pre- to post- the preparation training phase. Similarly, with muscle tension set as the outcome variable, a study by Luijcks et al. (2014) revealed that electromyographic activity of the trapezius muscle was significantly higher during a 3-min recording period when participants were awaiting the random occurrence of an electric shock of unknown intensity, compared to equivalent recording periods when they were certain that no shock was forthcoming. Taken together, these findings provide evidence that dedicated preparation and/or certainly about the nature of an upcoming stressor can help reduce reactivity across multiple physiological systems preceding stressful events.

In summary, evidence indicates that psychophysiological stress reactivity is influenced by the amount of prior information that an individual has about the stressor. When individuals have advanced awareness of the precise nature and timing of a stressor (e.g., Martins et al., 2015), and/or when they feel thoroughly prepared for the stressor (e.g., Wallace, 1984), their reactivity to the stressor is dampened. In contrast, when there is uncertainty surrounding stressors, such as the intensity or the timing being unknown, or the stressor being presented as a surprise, reactivity to the stressor is augmented (Luijcks et al., 2014). This research is useful as it can provide the basis for a psychophysiological prediction regarding mentally tough behaviour that I will test in this thesis. Specifically, it is reasonable to predict that if relative sensitivity to punishment and insensitivity to reward sensitivity is associated with mentally tough behaviour because this combination of traits promotes alertness to threats (Hardy et al., 2014), individuals possessing these traits should also be less reactive to stress. This is because the superior threat detection systems inherent in individuals who are sensitive to punishment and insensitive to reward make it more likely that they are alert to the precise nature of potential stressors than individuals who do not possess these traits. Being alert to possible stressors should reduce the element of surprise when the stressor manifests and increase time for mental preparation. Accordingly, it is expected that when reward sensitivity is low, increasing punishment sensitivity will be associated with reduced cardiovascular, neuromuscular and neuroendocrine reactivity to stress.

Psychophysiological Indices of Preparation for Action. There is a long history of psychophysiological research examining the event-locked patterns of physiological activity that characterize preparation for discrete motor tasks (for review see Requin, Brener & Ring, 1991). Of particular relevance to this thesis is research concerning phasic changes in heart rate during motor preparation. Seminal work in this field was conducted by John and Beatrice Lacey in the 1970's. In a series of reaction time experiments they noted that heart rate consistently decelerated during the period between the warning stimulus and the onset of movement (e.g., Lacey & Lacey, 1970, 1974, 1980). Moreover, they provided evidence that this phasic deceleration in heart rate is associated with behavioural proficiency, with faster reaction times being associated with greater preparatory heart rate deceleration (Lacey & Lacey, 1974). They argued that heart rate deceleration is associated with the intake of environmental stimuli (e.g., the adoption of an external focus of attention), and that it facilitates external information processing by reducing blood pressure, unloading the baroreceptors, and increasing the flow of environmental information to the brain (Brunia, 1993).

More recently, similar effects have been reported during the final moments of preparation for self-paced aiming sports. For example, heart rate usually decreases in the brief moments before a golf putt, with maximum bradycardia occurring when the putter and ball make contact (Cooke et al., 2014). More skilled golfers have a greater preparatory heart rate deceleration than less skilled golfers (Cooke, 2014). For example, Boutcher and Zinsser (1990) reported that expert golfers displayed a heart rate deceleration of around 20 beats per minute, whereas beginners showed a heart rate deceleration of around 15 beats per minute during the four interbeat intervals preceding putts. Similarly, Cooke et al., (2014) reported heart rate decelerations of around 20 beats per minute for experts and 10 beats per minute for novices during the six seconds preceding putts. Finally, Neumann and Thomas (2009) reported that elite, experienced and novice golfers reduced their heart rate by 12, 10 and 2 beats per minute, respectively, during the six seconds preceding putts.

While the magnitude of phasic heart rate deceleration might reflect the quality of preparation for golf putts, with greater deceleration corresponding to better preparation (e.g., greater intake of relevant information concerning line and length) and being associated with better performance, this measure may also be influenced by stress. Specifically, there is much evidence indicating that increased stress can have an adverse effect on preparatory physiological routines. For example, stressful events often disrupt sleep during preceding nights, such as shortening sleep, fragmenting sleep, and reducing rapid-eye-movement (deep) sleep (Akerstedt, 2006), even when one makes explicit effort to increase sleep duration as a deliberate pre-performance routine (Ansfield, Wegner & Bowser, 1996). Accordingly, it is reasonable to assume that stress could also have an adverse effect on phasic measures of motor preparation, such as preparatory heart rate.

Much anecdotal evidence indicates inability to slow heart rate during the final moments preceding discrete motor tasks performed under high-stress conditions. For example, the lauded English rugby union fly-half Johnny Wilkinson famously admitted to experiencing extreme anxiety when preparing to kick a crucial penalty in the 2007 World Cup, which was especially characterized by feeling and seeing his shirt moving from his racing heart beat ("Evening Standard Newspaper", 2007). Few research studies have examined the effects of stress on phasic heart rate deceleration. Cooke et al., (2014) did examine the effects of pressure, elicited by competition and rewards, on phasic heart rate during preparation for golf putts. They found that tonic heart rate increased from the low-pressure to the high-pressure condition but the rate of deceleration was unaffected. However, the strength of their pressure manipulation was mild and may have been diluted by performance being assessed as the average of 60 putts. Crucially, unpublished data from the same study (A Cooke, personal communication May 17, 2015) did reveal that preparatory heart rate deceleration was significantly disrupted (nearly abolished) in an additional “super-stress” condition where participants had a single-putt that they were required to hole in order to win £10. This provides the basis for another psychophysiological prediction regarding mentally tough behaviour that I will test in this thesis. Specifically, it is reasonable to predict that if relative sensitivity to punishment and insensitivity to reward sensitivity is associated with mentally tough behaviour because this combination of traits promotes optimal preparation (Hardy et al., 2014), individuals possessing these traits should display patterns of phasic heart rate deceleration that are robust (e.g., consistent) across both low- and high-stress conditions. This is because the superior preparation inherent in individuals who are sensitive to punishment and insensitive to reward make it more likely that they will be able to consistently execute their preparatory routine during high-stress conditions than individuals who do not possess these traits. Accordingly, it is expected that when reward sensitivity is low, increasing punishment sensitivity will be associated with reduced disruption to the phasic heart rate deceleration profile during high-stress.

Kinematic Indices of Preparation for Action. If patterns of phasic heart rate deceleration during the final moments preceding golf putts can reflect the amount of preparatory information processing, such as the planning of line and length (Neumann & Thomas, 2009), kinematic variables may also be (tentatively) interpreted as indices of motor preparation. This is because kinematic variables such as velocity and angle of the clubhead at impact are influenced by the direction and force commands determined by our preparatory motor program (Kutas & Donchin, 1977). There is much evidence to indicate that elevated stress can have an adverse effect on movement kinematics, possibly reflecting stress disrupting the accuracy of motor pre-programming. For example, Cooke et al., (2010) reported that increased stress was associated with an increase in lateral clubhead velocity, resulting in more putts being struck offline and finished wide of the hole. Similarly, Maxwell, Masters and Eves (2003) found that increasing demands on the working memory system (as occurs when one is stressed) decreased the smoothness of the downswing, possibly reflecting inefficient motor plans.

This provides the basis for a kinematic prediction regarding mentally tough behaviour that I will test in this thesis. Specifically, it is reasonable to predict that if relative sensitivity to punishment and insensitivity to reward sensitivity is associated with mentally tough behaviour because this combination of traits promotes optimal preparation (Hardy et al., 2014), individuals possessing these traits should display movement kinematics that are robust (e.g., consistent) across both low- and high-stress conditions. This is because the superior preparation inherent in individuals who are sensitive to punishment and insensitive to reward make it more likely that they will be able to consistently make accurate motor plans during high-stress conditions than individuals who do not possess these traits. Accordingly, it is expected that when reward sensitivity is low, increasing punishment sensitivity will be associated with reduced disruption to movement kinematics during high-stress.

Aims of the Thesis

The aims of the current research are based on the theoretical approach by Hardy et al. (2014) which examined the interactive effects of punishment and reward sensitivity on mental toughness behavior. They found that individuals who were high in punishment sensitivity and low in reward sensitivity performed well and had higher levels of mental toughness behavior as rated by their coaches in a cricket competition. Importantly, they suggested that individuals who had high level of punishment sensitivity and low level of reward sensitivity can detect threat early and they are better prepared for the next challenge (Manly et al., 2017). The aim of the current research was to further explore the relationship between the Reinforcement Sensitivity Theory and mental toughness behavior using a multidisciplinary approach (i.e., psychology, psychophysiology, movement kinematics, and performance). It is hypothesized that individuals who have high levels of punishment sensitivity and low levels of reward sensitivity should display less of an increase in heart rate under stress, less disruption to phasic heart rate deceleration under stress, less of an increase of muscle activity under stress, less disruption to movement kinematics under stress, less of an increase of cortisol level under stress, and perhaps better performance than individuals who are insensitive to punishment. Finally, to ensure the approach is not limited to rRST, the most popular quantitative measures of self-reported mental toughness will also be assessed to explore the relationship between self-report mental toughness and heart rate, muscle activity, movement kinematics, cortisol level, and performance.

Chapter 2

Study 1

Abstract

Aims: The current study was based on the theoretical findings of Hardy et al. (2014) which found that when individuals reported being sensitive to punishment and insensitive to reward display high levels of mentally tough behaviour under pressure (as rated by their coach). The aim of the current study was to use a multidisciplinary approach (i.e., psychology, psychophysiology, movement kinematics, and performance) to further examine why Reinforcement Sensitivity Theory relates to mentally tough behaviour. **Method:** The current study used a golf putting task in a low and high stress condition. Seventy (22 men; 48 women) right-handed novice golfers participated in this study. The acquisition phase had (10) blocks of (5) putts (totalling 50 putts), and the stress condition contained a single putt.

Findings: Our findings showed that individuals who were sensitive to punishment and insensitive to reward displayed better preparation for the stress putt indicated by lower heart rate reactivity, greater muscle activity, and smaller change in kinematic movement (e.g. clubhead angle).

Conclusion: According to Hardy et al. (2014) athletes high in punishment sensitivity and low in reward sensitivity perform better under pressure as rated by their coach. Results in the present study revealed that, individuals high in punishment sensitivity and low in reward sensitivity seem to be less perturbed by stress. These findings may in part explain why these individuals appear to display higher levels of mentally tough behaviour under pressure.

Introduction

Mental toughness can be defined as “the ability to achieve personal goals in the face of pressure from a wide range of different stressors” (Hardy et al., 2014, p. 2). Research has shown that some level of mental toughness is required for individuals to prosper across a range of domains including business (Gucciardi, Hanton, Gordon, Mallett, & Temby, 2015), the military (Arthur, Fitzwater, Hardy, Beattie, & Bell, 2015) and sport (Hardy, Bell, & Beattie, 2014). Research that focuses on understanding the psychological, physiological and behavioural mechanisms that underpin mental toughness, has the potential to inform subsequent interventions that develop mental toughness and optimize human performance. However, research in this area has tended to focus on these characteristics in isolation. The purpose of this chapter is to provide a multi-measure interdisciplinary analysis by considering how personality traits, psychological variables, and physiological responses interact to predict mentally tough behaviour.

Mental Toughness: Why is an Interdisciplinary Approach Needed?

To examine the development and maintenance of mental toughness, previous research has tended to use qualitative approaches in a range of athletic settings (e.g., Bull, Shambrook, James, & Brooks, 2005; Connaughton, Hanton, & Jones, 2010; Jones, Hanton, & Connaughton, 2002; Thelwell, Weston, & Greenlees, 2005). Meanwhile, quantitative research generally focussed upon the development and validation of self-report questionnaires, e.g. the Sport Mental Toughness Questionnaire (Sheard, Golby, Wersch, 2009), the Mental Toughness Index (Gucciardi et al., 2015) and the Mental Toughness Questionnaire 48 (Clough, Earle & Sewell, 2002). However, both qualitative and quantitative approaches to mental toughness research have received criticism. For example, qualitative studies have been criticised for their overuse, and for identifying a host of psychological characteristics that are associated with mental toughness (Anderson, 2011). Quantitative measurement has received criticism for poor validation and poor reliability. Further, as some research suggests that mental toughness is domain specific (e.g., Gucciardi, Gordon, & Dimmock, 2009a; Gucciardi, Gordon, & Dimmock, 2009b), then every sport type in the world should foster its own assessment of mental toughness (Anderson, 2011; Crust, 2007).

Other researchers (e.g., Hardy et al., 2014), also point out that the overuse of qualitative studies makes it difficult to determine between the causes, process, outcomes, and other correlates associated with mental toughness (see also Anderson, 2011). Further, Hardy et al. report that the general overuse of objective level of achievement as a marker of being mentally tough (e.g., Connaughton, Wadey, Hanton, & Jones, 2008; Coulter, Mallet, & Gucciardi, 2010 & Gucciardi, Gordon, Dimmock, & Dimmock, 2009) confuses talent, practice, skill level, and perhaps a host of other psychosocial and physiological variables that are associated with good performance. Hardy et al. make further note that the use of self-assessed mental toughness questionnaires is prone to social desirability and self-presentation bias. To advance research in this area, Hardy et al. concluded that there needs to be an evaluation as to whether mentally tough behaviour has occurred before one can claim the usefulness of self-report assessments of mental toughness (see also Andersen, McCullagh, & Wilson, 2007).

To assess mentally tough behaviour, Hardy et al. (2014) designed and tested an 8-item informant rating where coaches from English county level cricket teams rated statements about each of their cricketer's ability to maintain performance during challenging and high-pressure scenarios (e.g., "Player X is able to maintain a high level of personal performance in competitive matches…when people are relying on him to perform well"). Further, as Hardy et al. argue that mental toughness is a relatively stable disposition and unlikely to change quickly over time, these authors used the revised Reinforcement Sensitivity Theory (rRST; Gray & McNaughton, 2000) as a theoretical approach to predicting mentally tough behaviour. The rRST comprises of three neuropsychological systems: the behavioural activation system (BAS), behavioural inhibition system (BIS), and the fight flight freeze system (FFFS) (rRST; Gray& McNaughton, 2000). The behavioural activation system (BAS) regulates approach behaviours to rewarding appetitive stimuli such as personal goals, money or food. The fight flight freeze system (FFFS) is activated when an individual's main concern is to avoid threatening stimuli, especially if they contain potential for personal, social or physical harm. The behavioural inhibition system (BIS) resolves goal conflict between approach and avoidance behaviours (BAS and FFFS). For example, the BIS will resolve goal conflict when a stimulus contains both reward (obtaining a PhD), and threat (one has to defend their thesis to an external examiner).

Previous research using rRST to predict behaviour found that reward sensitivity was associated with mild reactions to stressful situations and higher levels of performance in combat situations (Perkins & Corr, 2006; Perkins, Kemp & Corr, 2007). Meanwhile, punishment sensitivity was associated with weaker performance in military combat tasks and avoidance of threatening situations (Perkins & Corr, 2006). Based on these findings, Hardy et al. (2014) hypothesized that MT behaviour would be associated with high levels of reward sensitivity and low levels of punishment sensitivity. However, in contrast to the hypothesis, Hardy et al. (2014) found that increasing levels of punishment sensitivity was associated with an increase in coach-rated mentally tough behaviour when reward sensitivity was low. When reward sensitivity was high, an increase in punishment sensitivity was associated with a decrease in coach-rated mentally tough behaviour. Importantly, Hardy et al. (2014) attributed these findings to punishment sensitive individuals being able to detect threat earlier and therefore having more time to plan an effective response. However, their sample pool was limited to elite male cricketers aged 16 to 18 years old. Hence it is unclear how these findings transfer across sport, performance level, gender and age.

To address these limitations, Beattie, Alqallaf, and Hardy (2017) replicated and extended the work of Hardy et al. (2014). These authors examined punishment and reward interactions in a sample of male and female swimmers with different levels of competitive experience with a much wider age range (12 to 22 years old). Beattie et al. found general support for Hardy et al.'s findings and in addition, found that punishment and reward sensitivities interacted to predict objective performance in the form of race times. Specifically, when reward sensitivity was low, increases in punishment sensitivity were associated with improvements in race time (such a relationship was found to predict mentally tough behaviour across Hardy et al.'s studies).

Furthermore, to examine the suggestion that punishment sensitive individuals are mentally tough, in part, because they detect threat early, Manley, Beattie, Roberts, Lawrence, and Hardy (2017) examined the interaction between condition (early and late threat warning) and punishment sensitivity upon performance. A precision hand-grip task was used in two studies. To explore the role of coping strategies in dealing with threat detection, participants in Study 1 were taught how to use imagery, muscle relaxation, and cue words to. In Study 2, there were no psychological skills training. Across both studies, participants were randomly selected into early or late threat warning condition. In the early warning condition, participants were told early in testing what would comprise the stress test. In the late warning group, participants were only told of the stress manipulation immediately before it took place. In study 1, punishment sensitivity positively related to performance in the stress condition when early threat warning was given. However, punishment sensitivity negatively related to performance in the stress condition when late threat warning was given. These results were replicated in study 2. Hence findings revealed that punishment sensitive individuals performed well under stress if they were given enough warning regardless of whether they were taught coping strategies (study 1) or not (study 2). However, in both studies, participants reported and benefited from using at least one coping strategy (even though in study 2 they were not explicitly taught to use them). Therefore, it appears that individuals who are punishment sensitive already have a set of cognitive strategies helping them to better deal with early threat detection (Manley et al., 2017; Hardy et al., 2014).

Psychophysiology of MT Behaviour

Based on Hardy et al.'s (2014) reasoning that mentally tough behaviour is associated with early threat detection and better preparation for a stressor (see also Manley et al., 2017), it seems reasonable to predict that individuals likely to produce mentally tough behaviour should display less stress reactivity when confronted with stressors than their less toughened counterparts. For instance, in two studies that used electric shock as an acute stressor, participants who were aware of the intensity of the upcoming shock displayed less heart rate reactivity (Martins, McIntyre, & Ring, 2015) and less electromyographical reactivity (Luijcks et al., 2014) than those for whom shock intensity was unpredictable (Martins, McIntyre, & Ring, 2015) and compared to a condition where no shock was forthcoming (Luijcks et al., 2014). Moreover, research has shown that heart rate reactivity decreases as amount of preparation for a stressor increases. For example, Wallace (1984) reported reduced preoperative heart rate in response to the stress of gynaecological surgery in individuals provided with a maximally informative surgery preparation booklet, compared to individuals undergoing the same procedure without receiving the preparation book. In other words, individuals who detect the precise nature of a stressor early/in advance, and who prepare for the stressor show dampened stress responses.

At a physiological level, reactivity to stress typically manifests as a reduction in activity of the parasympathetic nervous system and an increase in activity of the sympathetic nervous system, alongside increased neuromuscular activation (Obrsit, 2012). This is often characterised by an increase in heart rate (Kreibig, 2010), and an increase in muscle tension (e.g., Weinberg & Hunt, 1976). Accordingly, we expected that if early threat detection contributes to mentally tough behaviour, individuals relatively sensitive to punishment and insensitive to reward should display reduced muscular and heart rate reactivity to stressors. Some indirect evidence to support this prediction can be drawn from the work of Dienstbier (1989), showing that organisms exposed to stress during infancy and considered by Dienstbier to be “toughened” (possibly because infantile stressors increase sensitivity to punishment) displayed reduced emotional reactions to stressors during adulthood compared to non-toughened counterparts.

In addition to influencing stress reactivity, psychophysiological indices of mentally tough behaviour may also manifest in task-specific patterns of physiological activity that occur as part of the motor preparation for discrete movement tasks. Research in golf putting has shown a typical preparatory routine is associated with a phasic deceleration in heart rate in the final moments of preparation for the swing, with maximum bradycardia occurring at putter-to-ball impact (Cooke et al., 2014). Importantly, the magnitude of this phasic deceleration in heart rate during preparation for action has been associated with behavioural proficiency; golfers that are more proficient reliably display more pronounced preparatory heart rate deceleration than their less proficient counterparts (Cooke, 2014). For example, Neumann and Thomas (2009) compared the heart rate deceleration in elite, experienced, and novice golfers. During the 6 seconds prior to putting the ball, elite golfers’ heart rate decreased by 12 beats per minute, the experienced golfers had a heart rate deceleration of 10 beats per minute, whereas, the heart rate of the novice golfers decreased by only 2 beats per minute (Neumann & Thomas, 2009). Accordingly, we expected to observe an overall pattern of phasic deceleration in heart rate during the final moments preceding low-pressure putts. Importantly, if mentally tough behaviour is characterized by consistent preparation for a stressor, we expected this phasic deceleration in heart rate to remain consistent during a high-pressure putt in individuals relatively sensitive to punishment and insensitive to reward. To our knowledge, no previous study has examined such moderating roles of personality on phasic heart rate during motor preparation.

Finally, increases in psychological pressure also influence movement kinematics. For example, Cooke et al. (2010) reported that clubhead orientation was altered during high-pressure conditions, causing more putts to be missed wide of the hole. Similar pressure-induced disruptions to golf putting technique have also been reported by Maxwell, Masters and Eves (2003) and Moore et al. (2012). Accordingly, one can also hypothesize that downstream of its effects on cardiovascular and muscular indices of stress reactivity and motor preparation, relative sensitivity to punishment and insensitivity to reward should also be associated with consistent technique from low-stress to high-stress conditions. In contrast, individuals lacking this profile should be more susceptible to stress-induced changes in technique, such as increased clubhead angle at impact causing the most pressure-laden putts to be struck wide of the hole.

The Present Study

The present study is designed to provide a first comprehensive, interdisciplinary analysis of mentally tough behaviour. Building on the work of Hardy et al. (2014) we expect individuals with personality profiles that indicate a relative sensitivity to punishment and insensitivity to reward to display mentally tough behaviour, indexed by consistent or improved golf putting performance on transition from low to high-stress conditions. Importantly, we are testing putative psychophysiological and kinematic mechanisms that could underpin this behaviour for the first time. If punishment sensitive and reward insensitive individuals display mentally tough behaviour because of earlier threat detection, coping strategies, and better preparation, we hypothesize that they will display relatively low muscular and heart rate reactivity to higher levels of stress. We also hypothesize that their phasic heart rate deceleration and their movement kinematics will be unperturbed by the stressor, reflecting a consistent preparatory routine and technique in-spite of increased pressure. Finally, to ensure our approach was not limited to rRST, we also administered a range of the most popular quantitative measures of self-reported mental toughness. The extant quantitative literature in mental toughness would predict that these self-report measures should correlate with stress-induced changes in performance and our proposed psychophysiological and kinematic indices of mentally tough behaviour.

Method

Participants

Seventy participants (22 men and 48 women, M_{age}= 22.41, *SD*= 3.20) volunteered to participate in this study. Power analyses indicated that a sample of 70 would be sensitive enough to detect medium-size effects via linear regression analyses containing three predictor variables (i.e., punishment sensitivity, reward sensitivity, and their interaction term). Accordingly, our study was powered to detect interaction effects of similar magnitude to those revealed by Hardy et al., (2014). All participants were right-handed novice golfers. Participants were told that the purpose of the current study was to examine the effects of personality and learning in golf putting. All participants provided informed consent. The study was approved by a University research ethics committee.

Task

The study employed a golf-putting task. Participants putted balls from a distance of 2.5 m to a standard-size hole on a Huxley premier Returf Putting green. Participants used a KT25 Persimmon golf putter and a Slazenger Raw Distance 432 dimple pattern golf ball.

Design

The design consisted of an acquisition phase (ten blocks of five putts) and a test phase (one putt). Stress condition (i.e., final block of acquisition phase = low stress, test phase =

high stress) and epoch were the within-participant factors. An epoch is the amount of time before the movement when the psychophysiological variables were examined. To examine phasic changes, heart rate and muscle activity were analysed in 13 epochs (i.e., -6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) around movement initiation (Moore, Vine, Cooke, Ring, & Wilson, 2012; Neumann & Thomas, 2011).

Stress Manipulation

At the start of the experiment, participants were told that they would earn 50 pence (circa 62 cents) for each successful putt they made during the acquisition phase (a total of £25 or $32 could be won if participants were successful on every putt). To manipulate stress, on completion of the 10-block acquisition phase, participants were told that there was one additional and necessary putt to make. Participants were told that if they were successful in holing this final putt, their current earnings would be doubled. However, if they missed it, they would lose all their earnings. We then told the participants to digest this information for one minute before making their final putt.

Self-Report Measures

State Anxiety Manipulation Check

Mental Readiness Form-Likert (MRF-L, Krane, 1994). The MRF-L was used to assess competitive state anxiety. The MRF-3 was designed as a short form of the Competitive State Anxiety Inventory (CSAI-2; Martens, Burton, Vealey, Bump & Smith, 1990). Participants used an 11-point Likert scale to rate their cognitive anxiety (1= calm, 11= worried) and their somatic anxiety (1= relaxed, 11= tense). Krane (1994) reported correlations between the MRF-L and the CSAI-2 of 0.76 for cognitive anxiety and 0.69 for somatic anxiety, supporting the concurrent validity of this measure.

Personality

Reward and Punishment Sensitivity. The EPQR-S (Eysenck, Eysenck, & Barrett, 1985) is a 36-item self-report questionnaire which includes three subscales: extraversion, for example “Are you rather lively”; neuroticism, for example “Does your mood often go up and down”; and psychoticism, for example “Do you take much notice of what other people think”. Participants answered each question by responding with *Yes* or *No*. The EPQR-S scales have displayed good internal consistency (α = 0.77–0.88) and are strongly correlated (r = 0.71–0.96) with longer versions of the Eysenckian personality measure (Francis, Philipchalk, & Brown, 1991). Corr (2001) proposed the following transformations to measure reward and punishment sensitivity: reward sensitivity = (E x 2) + N + P), and punishment sensitivity = (12 – E) + (N x 2) – P), where E = extraversion, N = neuroticism and P = psychoticism. Hardy et al. (2014) reported internal consistencies for EPQR-S variables ranged from 0.78 to 0.85. In the current study the internal consistencies were 0.41 (psychoticism), 0.83 (neuroticism), and 0.86 (extraversion). Scores were therefore free to range from 0 to 48 for reward sensitivity and from –12 to 36 for punishment sensitivity

Mental Toughness Questionnaire-48 (MTQ48; Clough et al., 2002). The MTQ48 is a 48-item questionnaire which includes four subscales: challenge, commitment, control, and confidence, each containing 12 items. The MTQ48 uses a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Example items include: “Challenge usually brings out the best in me” (Challenge); “I usually find something to motivate me “(Commitment); “I generally feel in control” (Control); “I generally feel that I am a worthwhile person” (Confidence). Crust (2007) reported that the MTQ48 has an overall test-retest coefficient of 0.9 and internal consistencies of Control (0.73), Commitment (0.71), Challenge (0.71) and Confidence (0.80). In the current study the internal consistencies were: Control (0.77), Commitment (0.82), Challenge (0.71) and Confidence (0.82).

Mental Toughness Index (MTI; Gucciardi et al., 2015). The MTI is an eight-item unidimensional questionnaire. Example items include “I believe in my ability to achieve my goals”, “I strive for continued success” and “I can find a positive in most situations”. They are assessed by a 7-point Likert-scale from 1 (being false 100% of the time) to 7 (being true 100% of the time). The MTI has showed adequate internal reliability ($\alpha = 0.86$) in the study by Gucciardi et al. (2015). In the current study, the internal consistency was 0.81.

Sport Mental Toughness Questionnaire (SMTQ; Sheard et al., 2009). The SMTQ is a fourteen-item multidimensional questionnaire that includes three subscales: confidence, constancy and control. The questionnaire is assessed on a 4-point Likert scale from 1 (not at all true) to 4 (very true). Sample items from each subscale include, “I have unshakeable confidence in my ability” (Confidence); “I worry about performing poorly” (Control – reverse scored); “I am committed to completing the tasks I have to do” (Constancy). Sheard et al. (2009) reported good internal consistency (confidence $\alpha = 0.80$; control $\alpha = 0.71$; constancy $\alpha = .74$). In the current study internal consistencies were 0.77 for confidence, 0.56 for constancy and 0.65 for control.

The Brief Resilience Scale (BRS; Smith et al., 2008). The BRS is a six-item single factor assessment of resilience. Participants rate each of the six items (for example, “It does not take me long to recover from stressful event”) on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The brief resilience scale has shown good internal consistency ($\alpha = .81$) (Zimmermann, 2015). In the current study internal consistency reached .80.

Physiological Measures

Heart rate. Instantaneous heart rate was derived from an electrocardiogram (ECG) obtained using three silver/silver chloride electrodes (BlueSensor, Ambu, St Ives, UK) placed on the participant’s right collarbone, left collarbone and lowest left rib. The ECG signal was filtered (1-100 Hz; Bagnoli-4, Delsys, Boston, MA) and digitized at 2500 Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK).

Muscle activity. Muscle activity was derived from an electromyogram (EMG) measured using differential surface electrodes (DE 2.1, Delsys) affixed to the extensor carpi radialis and the flexor carpi ulnaris of the left arm, and a ground electrode (BlueSensor) on the left collar bone. The position of the electrodes was chosen based on previous research and pilot testing implicating these muscles in the golf putting stroke (Cooke et al., 2010; Cooke, Kavussanu, McIntyre, Boardley, & Ring, 2011). The signal was amplified (Bagnoli-4, Delsys), filtered (20-450 Hz) and digitized at 2500 Hz with 16-bit resolution (Power 1401), and captured by a computer running Spike2 software.

Movement Kinematics

A 12-camera reflective motion capture system (Nexus, Vicon, Oxford, UK) was used to measure the kinematics of the golf club and ball. Retro-reflective tape was placed on the ball, and retro-reflective markers (14mm, Vicon) were placed on the heal and the toe of the putter face, and at the base of the putter shaft. Their 3-dimensional positions (i.e., X, Y and Z axes) were recorded at a sample rate of 100 Hz by the motion capture cameras. We extracted five movement kinematic measures from these recordings. Backswing time (ms) and forward swing time (ms) were computed to assess the tempo of the swing. The impact velocity of the clubhead on the primary back-and-forth axis (mm per sec) and the peak velocity of the ball (mm per sec) were computed to assess the impact force of the swing and the resultant ball speed. Finally, the angle of the clubhead at impact (degrees) was computed to assess any angular rotation that may result in putts being pushed or pulled wide of the target. The five-putts in the low-stress condition were averaged to yield a single score for each error measure.

Performance Measures

Four performance errors -- radial (cm), distance (cm), direction (cm) and angle (degrees) – were computed for each putt in the low-stress and high-stress conditions using the motion analysis camera system. Radial error represented the distance between the end position of the ball and the middle of the hole. Distance error represented the difference between the end distance of the ball from the start point, and the distance between the start point and the hole. Direction error represented the end distance left or right that the ball finished from a straight line between the start point and the hole. Angle error represented the angle between the end position of the ball and a straight line between the start point and the hole, with the start point as a reference. The five-putts in the low-stress condition were averaged to yield a single score for each error measure. We also calculated the total percentage of putts holed in the stress condition.

Procedure

We first briefed each participant on the procedure and putting task (except the final putt condition) and obtained informed consent. Then, each participant completed the EPQR-S (Eysenck et al., 1985), the MTI (Gucciardi et al., 2015), the MTQ48 (Clough et al., 2002), the SMTQ (Sheard et al., 2009), and the BRS (Smith et al., 2008). The questionnaires were provided to each participant in a random order.

After questionnaire completion, participants were instrumented for physiological recordings. All the electrode locations on the participants' body were exfoliated and degreased using Nuprep gel and alcohol wipes prior to the electrodes being affixed. Next, we gave participants the putter and reminded them that for each putt they holed, they would receive 50 pence (62cents). Participants then completed 10 blocks of 5 putts, separated by 1 min rest in between each block. The experimenter retrieved the ball after each putt and replaced on the starting position ahead of the next trial, thereby reducing any unnecessary movements by the participants. Participants completed the MRF-L to rate their state anxiety immediately prior to the final block of 5 putts in the acquisition phase (low-stress condition). On completion of the final block of putts in the acquisition phase, the participant was informed about the money they had accrued during the acquisition phase. They were then informed that they had one more putt to make where they could double or lose their money (i.e., the stress manipulation). Participants completed the MRF-L again (high-stress condition) before attempting the final putt. On completion, the equipment was collected, and the participant was thanked and paid the earnings he or she had totaled if the final putt was holed. Each session took approximately 1 hour and fifteen minutes to complete. Participants were asked not to discuss the nature of the stress manipulation with any of their peers.

Data reduction

Individual trials within the continuous physiological recordings were identified using an optical sensor (S51-PA C10PK, Datasensor, Monte San Pietro, Italy), which detected the initiation of putts, and a microphone (NT1, Rode, Silverwater, Australia) connected to a mixing desk (Club 2000, Studiomaster, Leighton Buzzard, UK). Similar to previous studies (Cooke et al., 2014; Neumann & Thomas, 2011), we used the ECG and EMG signals to analyze heart rate and muscle activity in successive 500ms epochs during the 6 s before movement (i.e., -6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s). Heart rate was calculated from the intervals between the R-waves of the ECG, with the nearest inter-beat-interval to each epoch being used to indicate the instantaneous heart rate for that epoch. Muscle activity was calculated by rectifying the EMG signal and averaging over 500 ms windows, such that the mean activity between 6.25 and 5.75 seconds prior to movement was taken to indicate muscle activity 6 s before movement, and so on. These analyses were performed offline using Spike2 software. Individual trials within the continuous motion analysis recordings were identified manually based on the ball being located on the start point, and the markers on the putter being stationary and immediately behind the ball.

Statistical Analyses

Our state anxiety manipulation check, the performance measures, and the kinematic measures were analyzed by paired samples t-tests with stress condition (low, high) as the within-participant factor. Heart rate and muscle activity were analyzed by 2 Stress Condition (i.e., low, high) × 13 Epoch (i.e., -6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) ANOVAs. Significant effects were probed by polynomial trend analyses and planned post-hoc comparisons to compare the magnitude of any -6 s to 0 s changes in the physiological measures. Moderated Hierarchical Regression was used to examine the interactive effects of punishment and reward sensitivity on heart rate, muscle activity, movement kinematics and performance. These analyses are outlined in the results section. Finally, we performed correlation analyses to examine the putative relationships between quantitative MT measures (i.e., MTQ-48, SMTQ-14, MTI and BRS) and our candidate psychophysiological, kinematic and performance indices of MT behavior.

Results

State Anxiety Manipulation Check

Paired samples t-tests comparing anxiety in the low-stress and high-stress conditions indicated that state anxiety significantly increased from the low-stress condition ($M_{\text{cognitive}}$ = 3.51, SD = 2.27; M_{somatic} = 3.93, SD = 2.65) to the high-stress condition ($M_{\text{cognitive}}$ = 5.40, SD = 2.76; M_{somatic} = 5.67, SD = 2.68), ts(69) = -7.04 and -7.55, ps <.001. These results confirm that our stress manipulation was successful.

Heart Rate

Due to excessive artefacts, the electrocardiogram for two participants was unscoreable, leaving a sample of 68 for heart rate analyses. The result of a 2 Stress (low vs. high) x 13 Epoch (-6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) ANOVA computed on heart rate is depicted in Figure 1. There were main effects for stress, $F(1, 67) = 23.02$, $p < .000$, $\eta_p^2 = .25$, and epoch $F(12, 804) = 12.92$, $p < .001$, $\eta_p^2 = .162$. In the high-stress condition heart rate was significantly faster (M = 91.28, SD = 1.88 bpm) than in the low-stress condition (M = 84.75, SD = 1.36 bpm). The effect of epoch was best characterized by a linear polynomial trend ($p < .001$, $\eta_p^2 = .23$) showing a progressive decrease in heart rate (i.e., heart rate deceleration) during the six-seconds prior to impact (Figure 1). Importantly, there was also a Stress × Epoch interaction $F(12, 804) = 3.95$, $p < .05$, $\eta_p^2 = .056$, reflecting a difference in the rate of heart rate deceleration between the two stress conditions. Specifically, paired-samples t-tests (heart rate at the -6s epoch paired with heart rate at the 0s epoch) performed separately for each condition revealed a strong and significant heart rate deceleration in the low-stress condition ($M_{\text{heart rate -6 epoch}}$ = 87.65, SD = 10.72, $M_{\text{heart rate 0 epoch}}$ = 81.45, SD = 12.47, $t(68) = 7.01$, $p < .001$), and a modest non-significant heart rate deceleration in the high-stress condition ($M_{\text{heart rate -6 epoch}}$ = 92.81, SD = 16.52, $M_{\text{heart rate 0 epoch}}$ = 91.23, SD = 15.92, $t(67) = 1.16$, $p = .25$).

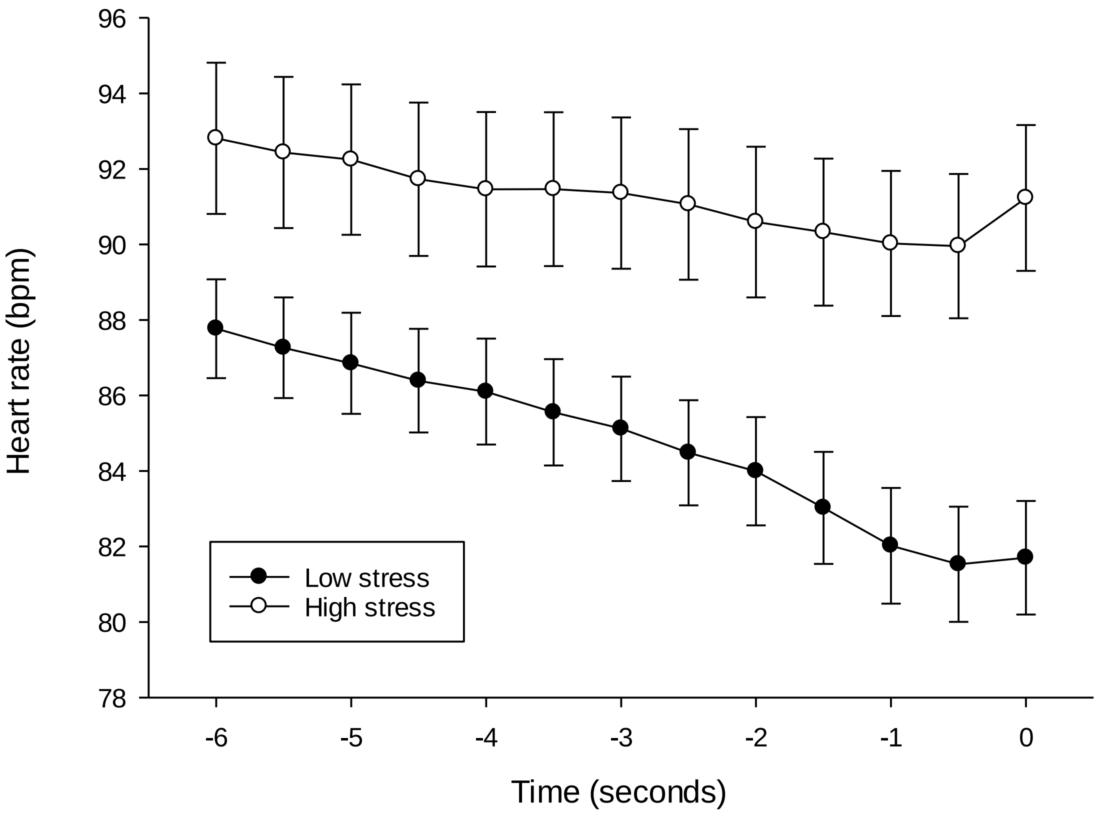

Figure 1. Heart rate Stress × Epoch interaction. Error bars indicate standard error of the means.

Muscle activity

Due to excessive artefacts, the electromyogram for one participant was unscoreable, leaving a sample of 69 for muscle activity analyses. The result of a 2 Stress (low vs. high) × 13 Epoch (-6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) ANOVA computed on extensor muscle activity is depicted in Figure 2. There was no main effect for stress condition $F(1, 68) = 2.23$, $p = .14$, $\eta_p^2 =. 03$, however there was a significant main effect for epoch $F(12, 816) = 45.15$, $p < .001$, $\eta_p^2 = .39$. The effect of epoch was best characterized by a quadratic polynomial trend ($p < .001$, $\eta_p^2 = .52$) showing an initially low and stable extensor muscle activity (-6 s to -1.5 s), followed by a sharp increase in extensor muscle activity during the final 1.5 s before impact (Figure 2). There was no Stress × Epoch interaction, $F(12, 816) = 2.13$, $p = .07$, $\eta_p^2 =.03$.

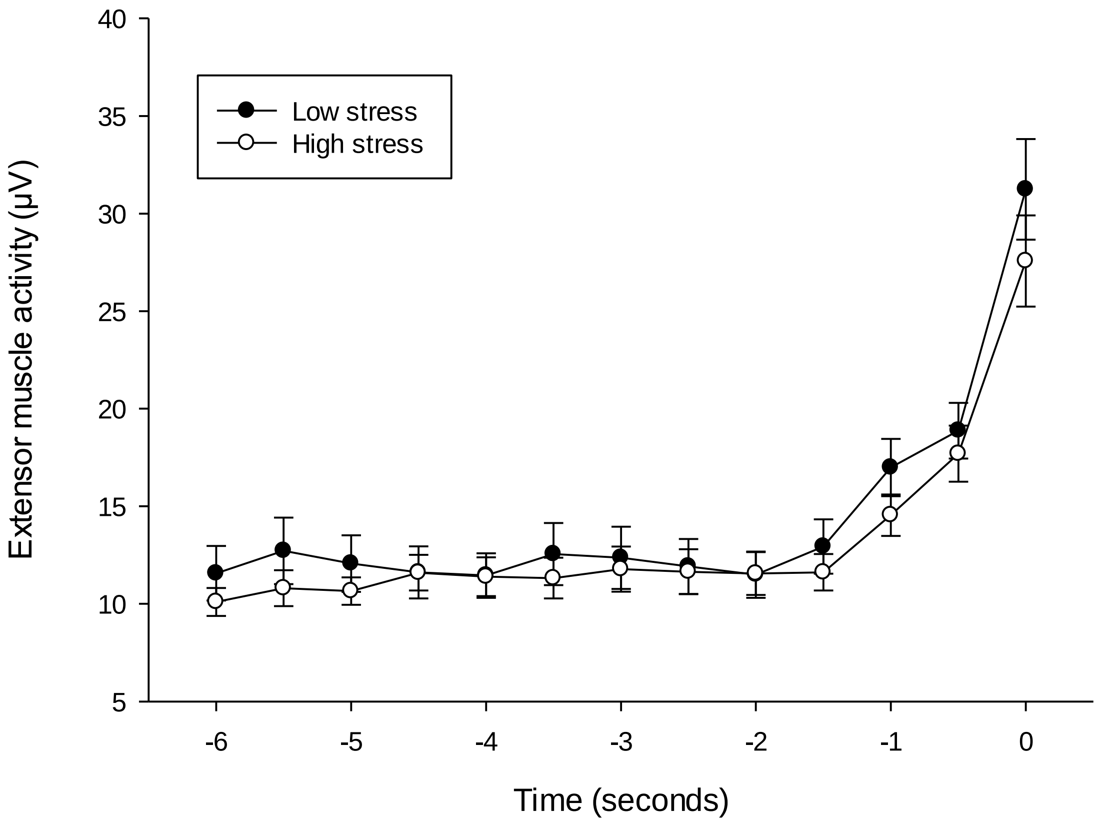

Figure 2. Extensor muscle activity Stress × Epoch interaction (ns). Error bars indicate standard error of the means.

For flexor muscle activity, there were significant main effects for stress, $F(1, 68) = 3.78$, $p < .05$, $\eta_p^2 = .05$, and epoch $F(12, 816) = 72.11$, $p < .001$, $\eta_p^2 = .51$. In the high-stress condition the flexor muscle activity was significantly greater ($M = 26.67$, $SD = 21.52$ µV) than in the low-stress condition ($M = 24.91$, $SD = 17.70$ µV). The effect of epoch was best characterized by a linear polynomial trend ($p < .001$, $\eta_p^2 = .60$) showing increases in flexor muscle activity during the six-seconds prior to impact (Figure 3). Importantly, there was also a Stress × Epoch interaction $F(12, 816) = 2.81$, $p < .022$, $\eta_p^2 = .040$, reflecting a difference in the rate of change in flexor muscle activity between the two stress conditions. Specifically, paired-samples t-tests (flexor muscle activity at the -6s epoch paired with flexor muscle activity at the 0s epoch) performed separately for each condition revealed a strong and significant increase in flexor muscle activity in the low-stress condition ($M_{\text{flexor muscle activity -6 epoch}}$ = 16.15, *SD* = 11.57, $M_{\text{flexor muscle activity 0 epoch}}$ = 50.75, *SD* = 30.17, $t(68) = -11.40$, $p < .001$), and a significant and even stronger increase in flexor muscle activity in the high-stress condition ($M_{\text{flexor muscle activity -6 epoch}}$ = 18.76, *SD* = 15.81, $M_{\text{flexor muscle activity 0 epoch}}$ = 57.02, *SD* = 37.35, $t(68) = -9.94$, $p < .001$).

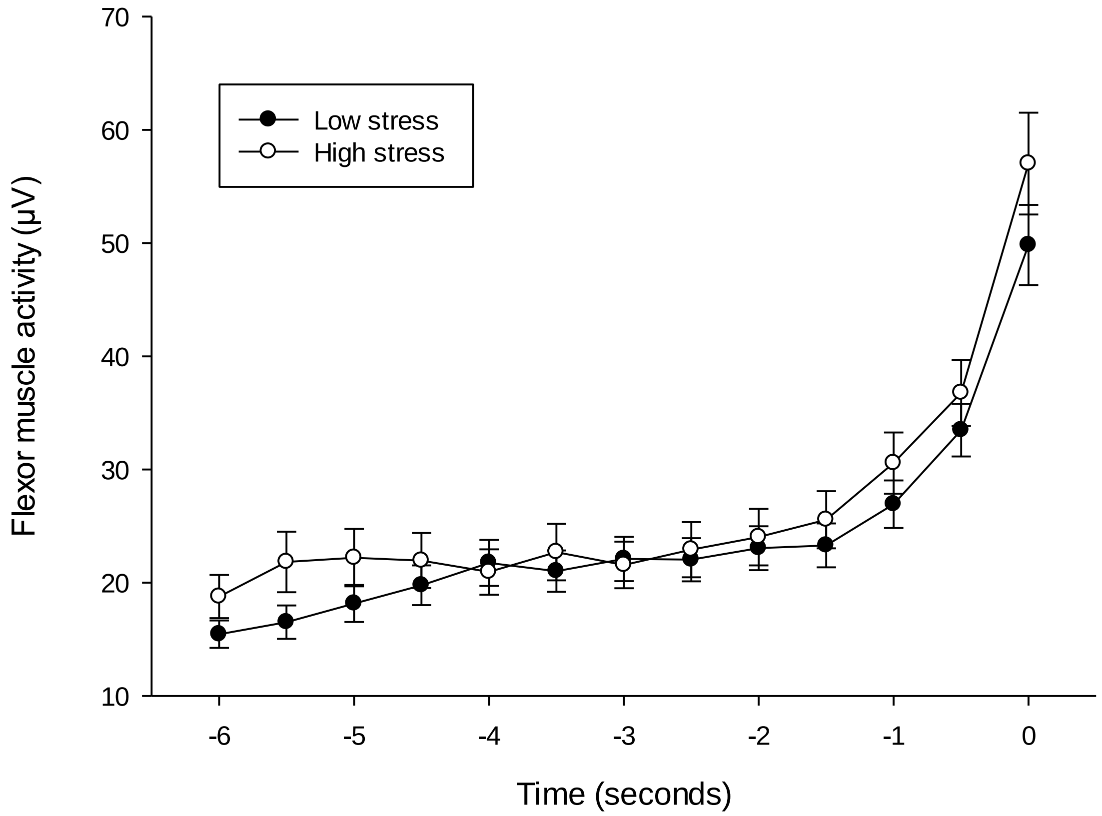

Figure 3. Flexor muscle activity Stress × Epoch interaction. Error bars indicate standard error of the means.

Performance

The results of paired samples t-tests conducted on our four measures of performance error are detailed in Table 1. In brief, there were significant increases in distance, direction and angular error from the low-stress condition to the high-stress condition, indicating that putts were more likely to finish long and wide of the hole in the high-stress condition. However, the induction of stress had no significant effect on our composite measure of mean radial error. Our crudest measure of performance (total percentage of putts holed) was also uninfluenced by the stress manipulation. In total, 95 out of the 350 total putts struck in the low-stress condition went in the hole (i.e., 27.14% holed), while 19 out of the 70 total putts stuck in the high-stress condition went in the hole (i.e., 27.14% holed).

Table 1. Performance in the Low-Stress and High-Stress conditions

	Condition		
Measure	Low-Stress Mean (SD)	High-Stress Mean (SD)	
Mean Radial Error (cm)	45.27 (22.32)	50.87 (37.74)	t(62) -1.20
Distance Error (cm)	36.99 (23.12)	49.20 (38.11)	t(62) -2.66**
Direction Error (cm)	5.54 (4.75)	8.69 (7.98)	t(62) -2.62**
Angle Error (degrees)	1.11 (0.92)	1.67 (1.53)	t(62) -2.43*

**p<.01, *p<.05

Movement kinematics

The results of paired samples t-tests comparing movement kinematic measures in the low and high-stress conditions are summarized in Table 2. In brief, there were significant increases in impact velocity, peak ball velocity, and clubhead angle at impact from the low-stress condition to the high-stress condition. This indicates that the putter was moving faster when it impacted the ball, the ball was hit harder, but with a clubhead impact angle that was more likely to send the ball off line during the high-stress condition. These effects are entirely compatible with the performance error results and can explain why more putts finished long and wide of the hole in the high-stress condition.

Table 2. Movement kinematics in the Low-Stress and High-Stress conditions

	Condition		
Measure	Low-Stress Mean (SD)	High-Stress Mean (SD)	
Backswing time (ms)	543.69 (138.73)	561.06 (195.88)	t(61) -1.31
Forward swing time (ms)	297.13 (72.16)	297.36 (74.8)	t(62) -.04
Peak ball velocity (mm/sec)	2202.29 (207.14)	2277.52 (319.8)	t(62) -2.22**
Impact velocity (mm/sec)	1292.26 (118.8)	1330.48 (168.8)	t(62) -2.35**
Clubhead angle at impact (degrees)	1.35 (.93)	1.96 (1.39)	t(62) -3.56**

$^{**}p<.01$, $^{*}p<.05$

Effects of Personality on Heart Rate, Muscle Activity, Performance and Movement Kinematics

To examine the hypothesised interactions, we used moderated hierarchical regression via PROCESS (Hayes, 2013). PROCESS allows moderation analyses to be conducted without manually creating the product term for the interaction. PROCESS also provides results of simple slope analysis to interpret any significant interactions (Cohen, Cohen, West, & Aiken, 2003). All data were subject to z-score transformation before analysis (Jaccard & Turrisi, 2003). Simple slopes were analysed and plotted at Mean ± *1SD*. Lower and upper bound 95% confidence intervals (CI) that do not encompass zero indicate significance at the .05 level. Alpha was set at .05 for all analyses.

Moderated hierarchical regression was used to examine the interactive effects of punishment and reward sensitivity on changes in heart rate, muscle activity (extensor, flexor), performance, and movement kinematics from low-stress to the high-stress condition. In all subsequent analyses punishment sensitivity was entered as the predictor variable and reward sensitivity as the moderator variable. The dependent variables were computed by the difference between the high and low stress for heart rate, muscle activity, and each performance and kinematic measure. These analyses thereby probed the extent to which personality can predict stress related reactivity. For heart rate, we also computed the difference in heart rate change from the -6 s to the 0 s epoch for each stress condition and performed the regression analyses on this additional dependent variable. This latter analysis thereby probed the extent to which personality can predict stress-induce changes to physiological indices of motor preparation.

Heart rate. To examine the effect of personality on heart rate reactivity to stress, we conducted moderated hierarchal regression analyses using punishment sensitivity, reward sensitivity, and the punishment × reward sensitivity interaction term for all 13 epochs. Although no main effects of punishment or reward were found at any of the epochs, there were significant interactions ($ps < .05$) at 7 out of the 13 epochs with the other 6 epochs showing strong trends ($ps < .11$). Additional inspection of the interaction plots showed that the nature of the interaction was the same at all epochs. For brevity, we averaged all the epochs to perform a single representative analysis. Results revealed no significant main effect for reward sensitivity ($\beta = -.056$, $p = .96$) or punishment sensitivity ($\beta = -.051$, $p = .97$) on heart rate reactivity. However, there was significant punishment by reward sensitivity interaction ($\beta = 3.58$, $p = .035$). The interaction shows that when reward sensitivity was low, as punishment sensitivity increased the stress-induced increase in heart rate reduced (i.e., lower stress reactivity). The simple slopes analysis approached significance ($\beta = -3.76$, $p =$

.06, 95% CI [-7.72, .19]). The opposite relationship was evident when reward sensitivity was high in that, stress-induced heart rate increased as punishment sensitivity increased. The simple slopes analysis was not significant (β = 3.57, *p* = .14, 95% CI [-1.25, 8.40]).

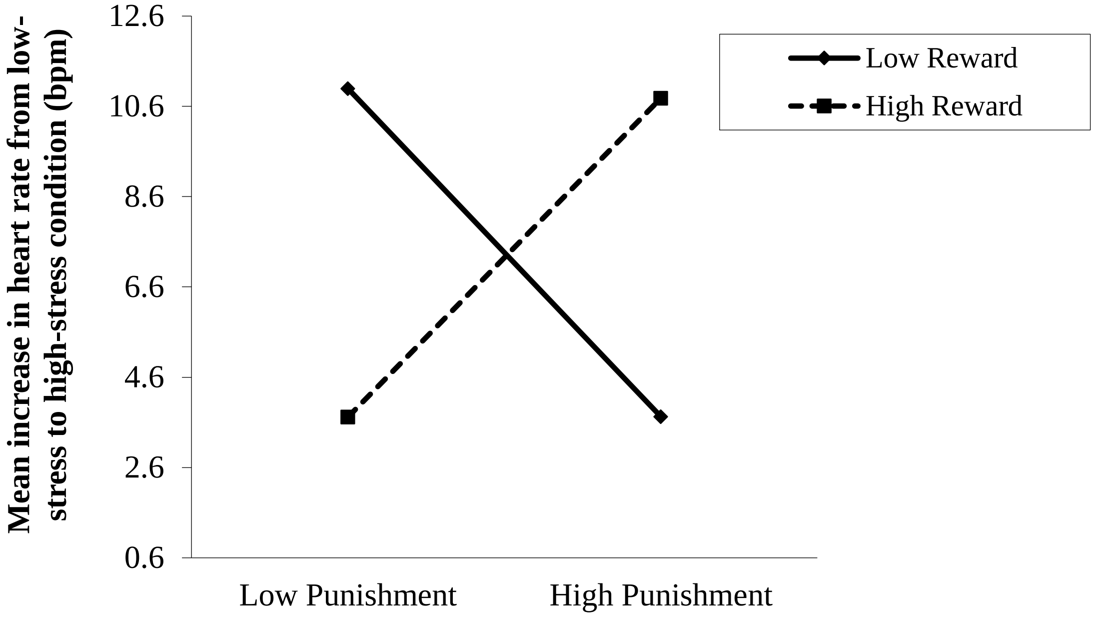

Figure 4. Interaction between punishment sensitivity and reward sensitivity predicting heart rate response to stress

To examine the effect of personality on the rate of phasic heart rate change across epochs, we conducted an identical analysis to predict the difference in the rate of change in heart rate from -6 s to 0 s between the low-stress and the high-stress condition. This analysis revealed no significant main effects for reward (β = -0.64, *p* = .66) or punishment sensitivity (β = -0.01, *p* = .99), and no reward by punishment interaction (β = -1.06, *p* = .54). Thus, personality was able to predict the extent of the observed stress-induced increase in heart rate as an index of stress reactivity but was not related to changes in heart rate across time (an index of motor preparation).

Extensor Muscle Activity. Moderated hierarchical regression analyses (in similar fashion to above) were conducted for each of the 13 epochs. Results revealed no significant main effect for reward sensitivity (β = -.120, *p* = .91) or punishment sensitivity (β= -.281, *p* = .81) on in extensor muscle activity. However, there was a significant punishment and reward sensitivity interaction at the final epoch only (i.e., muscle activity at the putter-and-ball impact) (β = -3.20, *p* = .02). The interaction shows that when reward sensitivity was low, the stress-induced increase in muscle activity was greater as punishment sensitivity increased. The simple slopes analysis approached significance (β = 2.96, *p* = .07, 95% CI [-.25, 6.18]). However, the opposite relationship was evident when reward sensitivity was high; the stress-induced increase in muscle activity was reduced as punishment sensitivity increased. The simple slopes analysis again approached significance (β = -3.52, *p* = .07, 95% CI [-7.48, .43]) (see Figure 5).

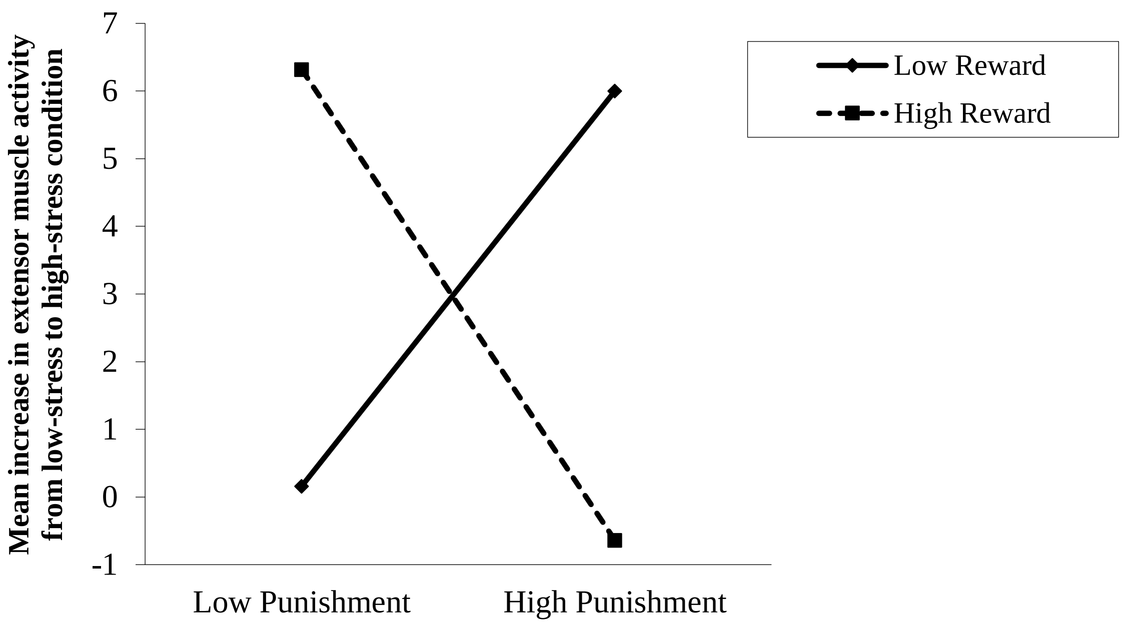

Figure 5. Interaction between punishment sensitivity and reward sensitivity predicting extensor muscle activity response to stress at the 0 s epoch (i.e., putter-ball-contact)

Flexor Muscle Activity. Moderated hierarchal regression analysis was conducted for each of the 13 epochs. There were no significant main effects for reward sensitivity at any of the epochs. However, there were significant main effects of punishment sensitivity (*ps* <.05) at 4 out of the 13 epochs, with trends (*ps* < .13) at a further 5 epochs. In all cases, the main effect of punishment showed that increasing punishment sensitivity was associated with a stress-induced increase in flexor muscle activity. There was also a significant punishment and reward sensitivity interaction ($\beta = -6.88$, $p = .017$) at the 0 s epoch only (but no main effect for reward [$\beta = .91$, $p = .70$] or punishment [$\beta = .236$, $p = .32$] sensitivity). The interaction shows that when reward sensitivity was low, the stress-induced increase in muscle activity was greater as punishment sensitivity increased. The simple slopes analysis indicated this slope was significantly different from zero ($\beta = 9.33$, $p < .01$, 95% CI [2.72, 15.9]). However, the opposite relationship was evident when reward sensitivity was high; the stress-induced increase in muscle activity was reduced as punishment sensitivity increased. The simple slopes analysis was not significant ($\beta = -4.59$, $p = .26$, 95% CI [-12.7, 3.52]) (see Figure 6).

For brevity, we averaged all the epochs to perform a single representative analysis for flexor muscle activity. Results revealed there was significant main effect for punishment sensitivity ($\beta =3.07$, $p = .026$) on flexor muscle activity. However, there was no significant main effect for reward sensitivity ($\beta =.128$, $p = .340$) on flexor muscle activity. Also, there was no significant punishment by reward sensitivity interaction ($\beta = -1.96$, $p = .22$) on flexor muscle activity.

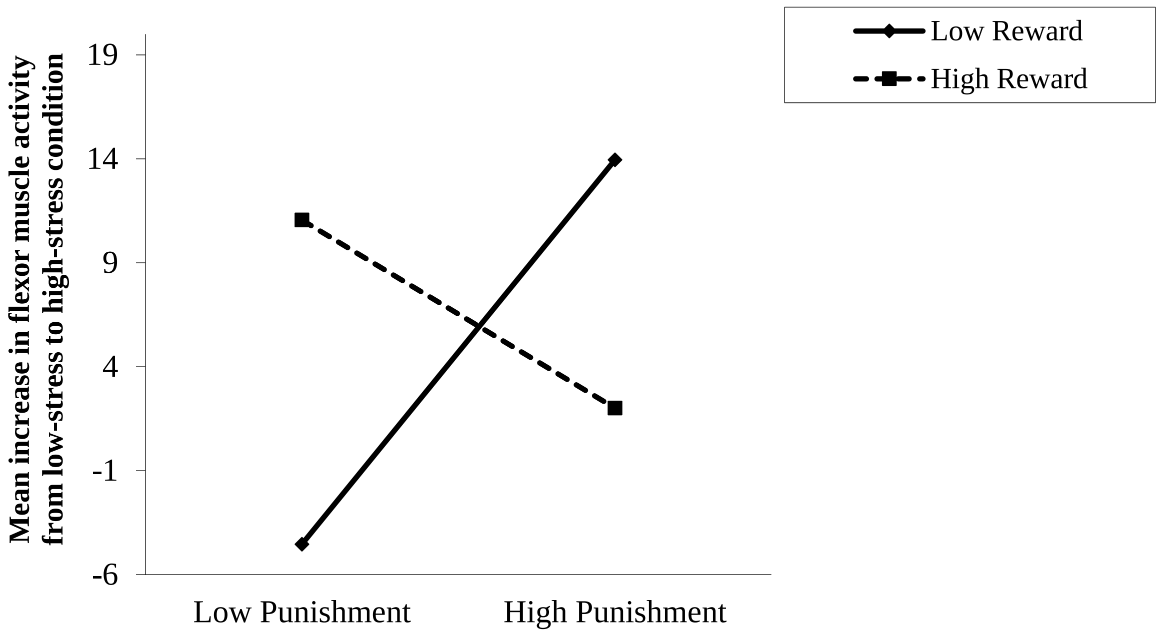

Figure 6. Interaction between punishment sensitivity and reward sensitivity predicting flexor muscle activity response to stress at the 0 s epoch (i.e., putter-ball-contact)

Performance. Moderated hierarchical regression analyses were conducted to see if personality could predict the condition differences in performance. Results revealed a main effect of punishment sensitivity on distance error which approached significance ($\beta = 105.07$, $p <. 06$). No other effects for personality and performance emerged.

Kinematics. Moderated hierarchical regression analyses conducted on the kinematic measures revealed a significant main effect of reward sensitivity on the stress-induced change in backswing time ($\beta = -32.90$, $p = .012$). In brief, high reward sensitivity was associated with a reduction in backswing time from low-stress to high-stress conditions. No other results were significant. There was no significant main effect for punishment sensitivity ($\beta = -.05$, $p = .77$) or punishment sensitivity ($\beta = .217$, $p = .23$) on clubhead angle at impact. However, there was a significant interaction between punishment and reward sensitivities on clubhead angle at impact (β = .495, p = .022). The interaction shows that when reward sensitivity was low, the stress-induced perturbation of clubhead angle was smaller as punishment sensitivity increased. The simple slopes analysis was not significant (β = -.28, p = .28, 95% CI [-.79, .23]). The opposite relationship was evident when reward sensitivity was high; the stress-induced perturbation of clubhead angle was greater as punishment sensitivity increased. The simple slopes analysis was significant (β = .71, p < .05, 95% CI [.12, 1.31]).

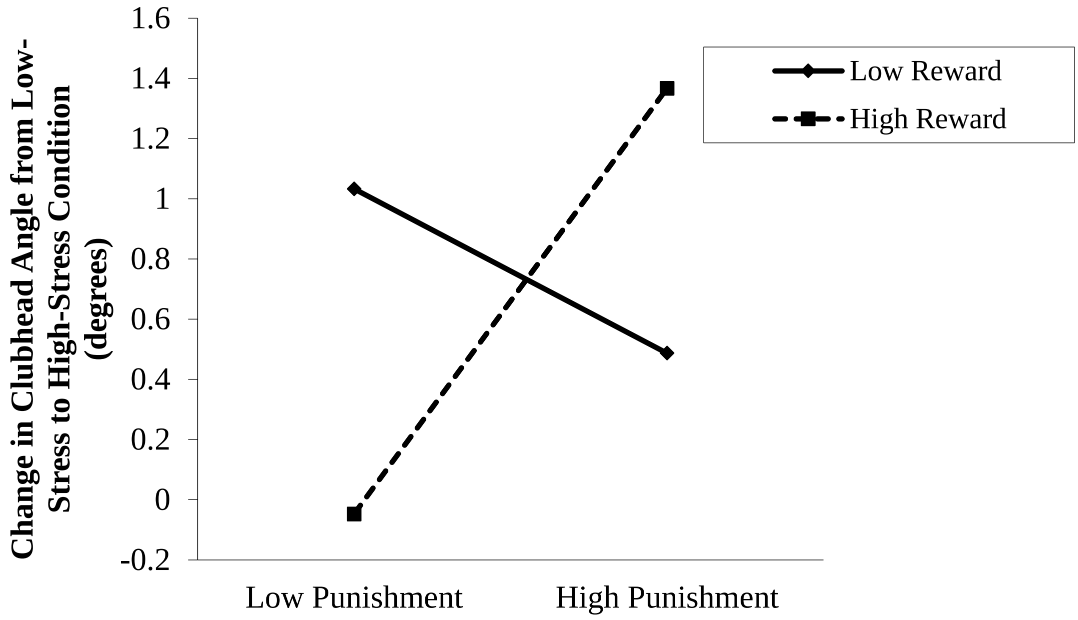

Figure 7. Interaction between punishment sensitivity and reward sensitivity predicting change in clubhead angle at impact from low- to high-stress

Relationships between quantitative measures of MT and psychophysiological, kinematic and performance measures.

The average scores for each of the self-report measures of personality and MT are presented in Table 3.

Table 3: Mean and standard deviation of personality and mental toughness self-reports

Measure	Mean	SD
Punishment	24.83	7.04
Reward	10.12	8.18
Mental toughness -48 (Challenge)	3.70	.51
Mental toughness -48 (Commitment)	3.65	.53
Mental toughness -48 (Control)	3.32	.43
Mental toughness -48 (Confidence)	3.48	.58
Sport mental toughness questionnaire (Confidence)	2.80	.43
Sport mental toughness questionnaire (Constancy)	3.15	.50
Sport mental toughness questionnaire (Control)	2.40	.60
Mental toughness index	5.40	.68

Correlation analyses assessed the relationships between quantitative measures of MT and our proposed psychophysiological, kinematic and performance indices of MT behaviour.

In total, 117 possible correlations were assessed (i.e., 4 subscales from MTQ-48, 3 subscales from SMTQ-14, the single subscale MTI and BRS × 13 psychophysiological, kinematic and performance outcome measures). Results revealed that out of a possible 117 correlations, only 4 correlations were significant. Specifically, the control subscale of the SMTQ-48 displayed a small and negative correlation (r = -.25, $p < .05$) with heart rate reactivity from low- to high-stress conditions. The control and confidence subscales of the MTQ-48 displayed small and negative correlations (r = -.27, $p < .05$; r = -.28, $p < .05$) with flexor muscle reactivity respectively from low- to high-stress conditions. Finally, the MTI-8 displayed a small and negative correlation (r = -.25, $p < .05$) with the change in backswing time from the low- to high-stress condition. Given the number of correlation analyses performed, the normal distribution curve would expect up to six correlations (i.e., 5% of 117) to emerge by chance. Since the total number of significant correlations did not exceed the number expected by chance, our data provide little evidence to endorse quantitative MT measures as reliable predictors of process and outcome variables associated with MT behaviour. However, it should be noted that the few correlations that did emerge were at least in the expected direction.

Discussion

The aim of the current study was based on previous research by Hardy et al. (2014), which examined the interactive effects of punishment and reward sensitivity on athletes mentally tough behaviour under pressure. Across two studies, Hardy et al. found that when reward sensitivity was low, increasing levels of punishment sensitivity was related to an increase in mentally tough behaviour. When reward sensitivity was high, increasing levels of punishment sensitivity related to lower levels of mentally tough behaviour. These findings were further verified in a sample of swimmers (i.e., Beattie et al., 2017). To significantly advance our understanding of research in this area, we followed Hardy et al.'s recommendations that research should focus on the cognitive neuroscience behind mentally tough behaviour by examining appropriate psychophysiological and behavioural markers that may underpin such behaviour. To do this, we assessed punishment and reward sensitivity with psychophysiological variables such as heart rate reactivity to stress, movement kinematics, muscle activity, and performance. To complement these variables, we also assessed a battery of self-report mental toughness questionnaires that should also relate to mentally tough behaviour.

Heart rate reactivity

For heart rate reactivity, we hypothesised that individuals who are sensitive to punishment and insensitive to reward should display reduced heart rate reactivity to our stressor. Overall, heart rate significantly increased on average by just over 6 beats per minute from low-stress to high-stress condition showing the validity of our stress manipulation. Interestingly individual differences showed that the highest heart rate reactivity was an increase of 44 beats per minute and the lowest was reactivity is where one person reduced their heart rate by 23 beats per minute.

With regards to our main hypothesis, results showed that when reward sensitivity was low, as punishment sensitivity increased heart rate reactivity reduced. This hypothesised result may provide a psychophysiological explanation of the findings of Beattie et al. (2017) and Hardy et al. (2014). In both of those studies coaches observed that athletes with low reward sensitivity and high punishment sensitivity display higher levels of mentally tough behaviour when competing under pressure. It was reasoned that athletes who are relatively sensitive to punishment and insensitive to reward may be more aware of and better prepared for stressors, and may be adept at employing coping strategies (Manley et al., 2017). Accordingly, in the current study, the participants who were sensitive to punishment and insensitive to reward may have processed the stressor and employed coping strategies which help lower their physiological response to threat.

Interestingly, the interaction shown in Figure 4 also revealed that when reward sensitivity was high, as punishment sensitivity increased heart rate reactivity increased. Although the simple slope for high reward sensitivity was not significant, it is interesting to note that those participants who were highly sensitive to reward and insensitive to punishment displayed a similar reduced heart rate reactivity to their punishment sensitive and reward insensitive counterparts. This unexpected finding may in part explain some previous research examining reward sensitivity and in combat situations. That is, Perkins et al. (2007)

and Perkins and Corr, (2006) found that reward sensitivity was associated with mild reactions to stressful situations and higher levels of performance in combat situations. Unfortunately, they did not examine interactive effects in their study, but if their participants who showed high reward sensitivity were also relatively insensitive to punishment, their findings would be compatible with ours. In their challenge and threat theory of stress appraisals, Jones, Meijen, McCarthy and Sheffield (2009) suggested that approach orientations associated with reward striving contribute to increased perceptions of resources and decreased perception of the demands when faced with stressors. Accordingly, following this line of thinking, it makes sense that the combination of high reward and low punishment sensitivity should also be associated with reduced reactivity to stressors.

In sum, the results support our first hypotheses that high levels of punishment sensitivity and low levels of reward sensitivity may be associated with better alertness to stressors, leading to an initiation of coping strategies and thus less reactivity to stress. Additionally, we also found a trend where high levels of reward sensitivity and low levels of punishment sensitivity are also predictive of reduced reactivity to stress, but in this case the mechanism is related to reward sensitivity reducing perceived task difficulty (and/or inflating one's sense of resources) rather than increasing alertness and preparedness.

Muscle activity

Another possible assessment of mentally tough behaviour could be gleaned by examining changes to muscle activity form low to high stress conditions. That is, mentally tough behaviour could be reflected by a consistent pattern of muscle activity from low-stress to high-stress conditions (cf. Weinberg & Hunt, 1976). We hypothesised that individuals who are sensitive to punishment and insensitive to reward should display minimum changes in muscle activity from low to high stress conditions. Overall, muscle activity increased from low-stress to high-stress conditions for flexor muscle activity but not for extensor muscle activity. However, we did not find any evidence that individuals who are sensitive to punishment and insensitive to reward display reduced muscle reactivity to stress as there was no significant interaction effect when muscle activity (averaged over 13 epochs) was the outcome variable.

Importantly, the only interaction that did emerge was at the final (ball contact) epoch, and it was in the opposite direction to our hypothesis (see Figure 5). Specifically, when reward sensitivity was low, as punishment sensitivity increased flexor muscle activity increased. However, when reward sensitivity was high as punishment increased, flexor muscle activity decreased. This means that those participants who showed the lowest heart rate reactivity to the stressor (i.e., those who were relatively high in punishment and low in reward sensitivity; and those who were relatively low in punishment and high in reward sensitivity) actually showed the greatest muscular reactivity at ball contact. This disconnect between heart rate and muscular activity can be interpreted to provide further evidence that the relatively low heart rates displayed by these participants are driven by psychological factors. The findings also question the validity of our measure of muscular activity as an index of psychological stress. Instead, since effects only emerged during the movement phase, it is likely that any effects of psychological processes on muscular activity were overridden by physiological effects associated with movement during the swing. For example, Cooke et al. (2014) found that forearm muscle activity at epochs specifically during moving (i.e., around putter-ball-contact) distinguished golf putting experts from novices, with higher muscle activity being associated with expertise and better technique. Accordingly, rather than reflecting stress reactivity and preparedness for stressors, our findings here could reflect those participants who showed the lowest cardiovascular reactivity to the stressors also displaying a functional increase in muscle activity from low- to high-stress conditions to help them improve their technique when the pressure was intensified.

Movement kinematics

Our movement kinematic results provide some evidence to support our interpretation of our muscle activity data. We hypothesised that individuals who are sensitive to punishment and insensitive to reward should display less disruption of movement kinematic variables when transitioning from a low to high-stress condition. Overall, there were no changes in the backswing time and forward swing time from low stress to high-stress condition however, there were significant increases in peak ball velocity, impact velocity, and clubhead angle at impact from low stress to high stress condition. When we tested our key regression-based hypotheses we found that when reward sensitivity was low, as punishment sensitivity increased, the stress induced disruption to clubhead angle at impact was decreased (i.e., kinematics were more consistent) however, the simple slopes analysis was not significant. Conversely, when reward sensitivity was high, as punishment sensitivity increased the stress induced disruption to clubhead angle at impact was augmented (i.e., kinematics were more perturbed), and the simple slopes analysis was significant.

Importantly, the nature of this interaction indicates that once again, the standout participants, this time in terms of displaying the most consistent clubhead angle across the stress conditions, were those who were relatively sensitive to punishment and insensitive to reward, and those who were relatively sensitive to reward and insensitive to punishment. Accordingly, the elevated muscle activity at impact displayed by these participants could be functional, in terms of helping ensure that their putter-head alignment was not disrupted in the high-stress condition. Misalignment of the putter-head at impact has been identified as a key reason for stress-induced impairment in putting performance among novices (Cooke et al., 2010). Our data imply that personality traits could be a protective factor against this common cause of stress-induced golf-putting failure. However, while this finding offers some support for our kinematic predictions, personality was unable to account for the stress-induced changes in peak ball velocity and impact velocity. Thus, we provide only partial support for our kinematic hypotheses.

Performance

We assessed performance in multiple ways (successful putts, distance, direction, and angular error). We hypothesised that individuals who are sensitive to punishment and insensitive to reward should display maintain high level of performance from low to high stress condition. With regards to performance, interestingly no changes were observed in the number of putts made in the low and high stress condition (27% of the putts were holed in both conditions). However, a more refined assessment of performance may be found in data examining distance, direction, and angular error.

Overall, there were significant increases in distance, direction and angular error from low-stress to high-stress condition, indicating that putts were more likely to finish long and wide of the hole in the high-stress condition. However, the induction of stress had no significant effect on our composite measure of mean radial error. Results also revealed that reward and punishment sensitivity was unrelated to performance. The finding does not support our hypothesis nor the findings of Beattie et al. (2017), who showed that individuals who were sensitive to punishment and insensitive to reward were performed well under stress. These performance results are also in contrast to our muscular activity and clubhead angle findings, which both revealed interactions that would imply that participants who were sensitive to punishment and insensitive to reward (and those who were sensitive to reward and insensitive to punishment) might have performed better under stress. It is possible that our kinematic and psychophysiological measures are more sensitive to subtle changes than our rather crude performance measures. Further, since our participants were novices, one might argue that significant impairments in performance under stress are unlikely, since their overall performance level is likely to be low and highly variable even in the low-stress condition. This is verified by the fact that only 27% of putts were holed. PGA tour professional golfers reliably make over 50% of putts from the same distance, with the top-ranked putters holing over 80% (https://www.pgatour.com/stats/stat.346.html), and they play on undulating greens, whereas our putting surface was flat.

However, there is an alternative possibility. It should be noted that Manley et al. (2017) found that increasing punishment sensitive was only beneficial for performance when participants were given sufficient time to prepare for a stressor. In the current study, participants were informed of the high-stress condition only one minute before they had to attempt their final all-or-nothing putt. While on the one hand, this warning should have given them clarity about what the stress condition entailed (i.e., awareness of the precise nature stressor, hence the opportunity for reduced heart rate reactivity) it may not have afforded sufficient time for proper preparation for performing under pressure. This line of thinking is considered further in relation to our results for phasic heart rate deceleration.

Phasic heart rate deceleration

The psychophysiological index that we expected to provide the most insight to preparation for stress was our measure of phasic heart rate deceleration 6 seconds before the putts. Previous research has shown that golfers that are more proficient tend to display more pronounced preparatory heart rate deceleration than their less proficient counterparts (Cooke, 2014). Although this phenomenon may associate with golfing experience, these profiles may also be apparent in individuals who undergo a consistent and effective preparatory routine (e.g., Moore, Vine, Cooke, Ring & Wilson, 2012), where stable heart rate deceleration profiles across low and high-stress conditions are indicative of stress having no adverse effect on movement preparation. Accordingly, we hypothesised that individuals relatively sensitive to punishment and insensitive to reward would display consistent phasic heart rate deceleration profiles across the low and high-stress conditions. This was not supported.

Overall, phasic heart rate deceleration was disrupted by the stress manipulation, as participants demonstrated less bradycardia in the final moments before the high-stress putt compared to the low-stress putts. Importantly, this was not predicted by punishment sensitivity or reward sensitivity, and there was no punishment and reward interaction. Accordingly, there was no type of participant who was consistently resilient to stress-induced changes to psychophysiological indices of movement preparation.

It should be noted that in previous studies where increasing punishment sensitivity has been linked to more mentally tough behaviour under stress due to increased preparation, more extensive warnings about the stressors have been provided than the mere one-minute warning that participants in our study were given. For instance, Manley et al. (2017) found that increasing punishment sensitivity had a beneficial effect on performance under stress when participants were briefed about the stress condition at the start of their experiment, before an extensive low-stress training phase. However, increasing punishment sensitivity tended to have an adverse effect on performance under stress when details of the stress manipulation were withheld until immediately before the high-stress condition. Although we afforded one-minute of preparation for stress in this study, our approach is clearly more similar to the "late" than the "early" threat warning conditions from Manley et al.'s (2017) study. It is possible that punishment sensitive individuals are only able to prepare optimally for a stressor if they are given sufficient advance warning. More warning of the threat may have been required if we were to support our prediction that punishment sensitive and reward insensitive individuals would maintain a consistent pre-performance routine from low- to high-stress. This hypothesis will be tested more directly in chapter 3.

Self-report MT

We hypothesised that there should be a multitude of significant correlations between self-report assessments mental toughness and our outcome variables. However, the results showed that only 4 correlations out of a possible 117 correlations were significant in the current study (less than would happen by chance alone). These results indicate that self-report assessments of mental toughness could not account for any of our significant findings. However, as noted below, perhaps our stress manipulation was not strong enough for these relationships to emerge. Hence we retest these hypothesised relationships in chapter 3 before commenting any further here.

Conclusion

To conclude, as far as we are aware, this study is the first to examine a comprehensive and interdisciplinary analysis of mentally tough behaviour. Partial support was found for our hypotheses that participants who had high level of punishment and low levels of reward sensitivity would show diminished physiological reactivity when placed under stress. This may go some way in explaining the results from Beattie et al. (2017) and the work of Hardy et al. (2014). Punishment and reward sensitivities did not interact in relation to predicting performance, hence failing to support the work of Beattie et al. (2107). However, there was some evidence that individuals with high levels of punishment sensitivity and low levels of reward sensitivity were able to maintain some level of performance consistency in relation to maintaining a consistent clubhead angle at ball contact.

However, there are limitations to the current study that are addressed in the subsequent chapter. For example, some of the participants in the current study did not earn a lot of money before the stress putt (i.e., less than £5). Hence the prospect of potentially losing a small sum of money may not have been particularly stressful. Further, it may also be noted that participants in the current study had very little time to prepare for the stress putt (i.e., 1 minute). Hence making direct comparisons to previous research in this area is problematic (e.g., Beattie et al., 2017; Hardy et al., 2014; Manley et al., 2017). This study has also provided a rationale for extending our multi-measure approach to include measures of challenge and threat appraisals to test our ideas about why reward sensitivity and punishment insensitivity appeared beneficial in some areas of this study. The disconnect between heart rate reactivity and muscle activity also open the door for an additional measure of stress reactivity to add further rigour. Hence the purpose of chapter 3 was to replicate and extend these findings where the nature of the stressor was explained to the participants at the outset of testing and that the nature of the threat was somewhat more severe than the current study manipulated.

Chapter 3

Study 2

Abstract

Aims: Based upon the results from Chapter 2, we extended our examination of mentally tough behaviour via a different stress manipulation and extended our examination of psychophysiology to include hormonal stress responses (i.e., cortisol). Chapter 3 re-examined the stress manipulation by asking participants to putt in pairs. Prior to testing, the participants were given a lump cash sum of £60 and were told that for each of the next 60 putts they missed (30 putts each), they would forfeit £1 from their combined pot. In the stress condition, participants had to make one more putt each. If they both made the putt we would double their money, if one person made the putt they would keep their money. If they both missed the final putt they would lose all their money.

Method: One hundred and four (66 male; 38 female) right-handed novice golfers participated in this study. Participants performed as a pair and made 10 practice putts each (no consequences), 30 putts (where £1 was forfeited for missing a putt), followed by another 5 practice putts (no consequences), followed by a single putt (where they could double, keep, or lose all their money). We collected saliva to assess individual differences in stress hormone production immediately after testing and at rest 24hrs later. All participants were told at the start of testing as to what the stress test entailed, hence giving them early warning. Other than not recording self-report levels of resilience, all other assessments were identical to that of Chapter 2.

Findings: Our main findings revealed that individuals who were sensitive to punishment and insensitive to reward displayed better preparation for the stress putt indicated by consistent phasic heart rate deceleration and reduced angular error (better performance). However, neither personality nor the stress manipulation predicted cortisol.

Conclusion: It appears that we were able to manipulate a higher level of stress to that of Chapter 2.

Introduction

Mentally tough individuals are considered to have "the ability to achieve personal goals in the face of pressure from a wide range of different stressors" (Hardy et al., 2014, p. 2) and possess attributes that enable them to thrive in domains such as business (Gucciardi, Hanton, Gordon, Mallett, & Temby, 2015), the military (Arthur, Fitzwater, Hardy, Beattie, & Bell, 2015) and sport (Hardy, Bell, & Beattie, 2014). This Chapter builds upon our previous efforts in this area (i.e., Chapter 2) by further extending our interdisciplinary approach to include assessment of hormonal responses to stress and by increasing the potency of our stress manipulation.

Mental Toughness: Qualitative and Quantitative Approaches

Extant mental toughness research has predominantly adopted either a qualitative approach, or a quantitative approach that is focused upon developing mental toughness questionnaires. Qualitative studies typically interview individuals to examine their perspectives on mental toughness, and typically result in a long list of mentally tough attributes such as "ability to withstand adversity", "coping with adversity", "focusing under pressure", "never giving up", and being self-motivated (e.g., Bull, Shambrook, James, & Brooks, 2005; Connaughton, Hanton & Jones, 2010; Jones, Hanton, & Connaughton, 2002; Thelwell, Weston, & Greenless, 2005). While this approach may contribute to a definition of mental toughness, it can be criticised for the long list of characteristics that it yields, many of which are difficult to measure (Anderson, 2011). Furthermore, since mental toughness is associated with high levels of achievement, when probing for mentally tough characteristics, previous studies have tended to examine populations that display high levels of achievement (i.e., elite level athletes). This is potentially problematic because while the characteristics revealed may be associated with mental toughness, they could just as easily reflect talent, practice, skill level, discipline, and motivation, which are also associated with high achievement (Hardy et al., 2014).

Quantitative mental toughness research has adopted an alternate approach by concentrating on the development of self-reported mental toughness measures. However, the measures that have resulted – typically informed by attributes yielded from qualitative studies – have been plagued by poor validation, poor reliability, and weak predictive utility (Anderson, 2011; Crust, 2007). Measures such as the Mental Toughness Questionnaire-48 (Clough, Earle & Sewell, 2002) are also said to confuse the causes, effects, outcomes and characteristics of mental toughness, and are highly prone to social desirability and self-presentation bias (Hardy et al., 2014). In summary, if we are to move forwards in our understanding of the mechanisms underpinning mental toughness, then consideration to other areas of psychology could prove fruitful.

Mental Toughness: A Personality Approach

Dissatisfied with the dominant quantitative and qualitative approaches to mental toughness research, Hardy and colleagues (2014) conducted a seminal program of research adopting a personality and behavioural approach. Specifically, they used the revised Reinforcement Sensitivity Theory (rRST; Gray & McNaughton, 2000) as a theoretical model to predicting mentally tough behaviour. The rRST comprises of three neuropsychological systems: the behavioural activation system (BAS), behavioural inhibition system (BIS), and the fight flight freeze system (FFFS) (rRST; Gray& McNaughton, 2000). The behavioural activation system (BAS) regulates approach behaviours to rewarding appetitive stimuli such as personal goals, money or food. The fight flight freeze system (FFFS) is activated when an individual's main concern is to avoid threatening stimuli, especially if they contain potential for personal, social or physical harm. The behavioural inhibition system (BIS) resolves goal conflict between approach and avoidance behaviours (BAS and FFFS). For example, to obtain a PhD (reward), one has to defend their thesis to an external examiner (social threat).

Their approach was informed by research by Perkins, Kemp and Corr (2007) who showed that reward sensitivity was positively associated with performance during a military combat scenario, while punishment sensitivity was negatively associated with performance. It could be reasoned that high levels of reward sensitivity promote approach motivation towards personal goals, while low levels of punishment sensitivity reduce the potential for an individual to be distracted by threats that could compete for attentional resources or prompt them to deviate from their goal.

To test their hypothesis, Hardy and colleagues assessed trait reward and punishment sensitivities of 410 high-level cricketers and compared them with an informant rating of mentally tough behaviour provided by their coach. In contrast to their hypothesis, Hardy et al. (2014) found that increasing levels of punishment sensitivity was associated with an increase in coach-rated MT behaviour when reward sensitivity was low. When reward sensitivity was high, an increase in punishment sensitivity was associated with a decrease in coach-rated MT behaviour. Importantly, Hardy et al. (2014) attributed these findings to punishment sensitive individuals being able to detect threat earlier and therefore having more time to plan an effective response. This effect has since been replicated in a sample of competitive swimmers (Beattie, Alqallaf & Hardy, 2017). Moreover, the suggestion that punishment sensitivity and early threat detection combine to support optimal performance was recently supported by Manley, Beattie, Roberts, Lawrence and Hardy (2017). Specifically, they found a positive relationship between punishment sensitivity and performance under stress but only when individuals were given advanced notice of the upcoming stressor.

In sum, this personality-based approach to mental toughness is promising as personality measures of reward and punishment (measured via assessments of extraversion, neuroticism and psychoticism) should be at lower risk of social desirability bias than self-report measures of mental toughness (e.g., who is not mentally tough?). They also offer a theoretical mechanism to explain behaviour, and the approach appears to have some predictive utility. In addition, the theoretical mechanisms advanced by Hardy et al. (2014) can be probed in more detail by objective psychophysiological indices that could provide a more direct mechanistic explanation of behaviour. The identification of psychophysiological associates of mental toughness is desirable as they could provide the basis for interventions (e.g., biofeedback) to encourage mentally tough behaviour.

Mental Toughness: A Psychophysiological Approach

In Chapter 2, we presented the first multi-measure psychophysiological analysis of mentally tough behaviour. Specifically, based on the research by Hardy and colleagues (i.e., Beattie et al., 2017; Hardy et al., 2014), we predicted that individuals with relative sensitivity to punishment and insensitivity to reward would display reduced physiological reactivity to a stressor and more consistent preparatory physiological and kinematic responses than individuals displaying other reward and punishment personality profiles (e.g., high in both or low in both). The reasons were twofold. First, participants who have personality profiles that relate to higher levels of mentally tough behaviour may respond to threat with lower psycho-psychophysical reactivity. Hence, they seem to perform better under stress. Second, being aware of the precise nature of a stressor in advance has been associated with reduced heart rate reactivity to that stressor (Martins, McIntyre & Ring, 2015). If we supported this prediction, we reasoned that it would add evidence to Hardy et al.'s (2014) claim that high levels of punishment sensitivity increase the likelihood of individuals detecting and preparing for stressors in advance.

Our results revealed mixed support for our hypotheses. Specifically, when reward sensitivity was low, increasing punishment sensitivity was associated with reduced heart rate reactivity, defined as the increase in heart rate from five low-stress golf putts to a single high-stress golf putt whose outcome determined whether participants doubled or lost the cash payment that they were expecting to receive on completion of the study. However, interestingly, there was also a trend indicating that when reward sensitivity was high, decreases in punishment sensitivity were associated with reduced heart rate reactivity. This latter finding could present a mechanism to explain Perkins, Kemp and Corr's (2007) observation that reward sensitively positively predicts performance, and punishment sensitivity negatively predicts performance.

We also measured muscle activity and found a similar interaction except here, when reward sensitivity was low, increasing punishment sensitivity was associated with increased muscular reactivity, defined as the increase in forearm muscle activity the low-stress to the high-stress putt. When reward sensitivity was high, decreases in punishment sensitivity were associated with increased muscular reactivity. Since increased muscular reactivity could also be part of the physiological stress response (Weinburg & Hunt, 1976), these results appear to contradict our heart rate findings. However, it is worth nothing that these interactions for muscle activity only emerged in the 500ms window around putter-to-ball impact, so it is likely that any stress effects on muscle activity were superseded by the movement demands of the task. Indeed, this increased muscle activity on impact demonstrated by individuals showing either high reward and low punishment or low reward and high punishment personality profiles could have been functional in helping them achieve a crisper contact and accelerate through the ball in the high-stress condition.

This interpretation is supported by a final interaction that emerged for clubhead angle at impact, one of our kinematic variables. Specifically, when reward sensitivity was low, there was a weak and non-significant trend for increasing punishment sensitivity being associated with a more consistent clubhead angle (reduced perturbation to technique) across the low-stress and the high-stress conditions. When reward sensitivity was high, there was a significant effect where decreases in punishment sensitivity were associated a more consistent clubhead angle across low-stress and high-stress condition.

In short, our findings provided a more nuanced picture than that revealed by Hardy and colleagues. We support the suggestion that relative sensitivity to punishment and insensitivity to reward could be associated with mentally tough behaviour and provide mechanistic evidence to imply that this is due to reduced cardiovascular reactivity to the stressor, and adaptive changes to muscular activation to help minimise disruption to swing kinematics during the crucial high-stress putt. However, we also support Hardy et al.'s (2014) original (yet unsupported) prediction that relative sensitivity to reward and insensitivity to punishment should be associated with optimal outcomes. This is because individuals displaying this personality profile where characterised by the same cardiovascular, muscular and kinematic profiles as their low reward and high punishment sensitive counterparts.

To further interrogate the findings reported in Chapter 2, this experiment set out to extend our psychophysiological approach. Specifically, we assessed cortisol to provide a hormonal index of stress reactivity. If our heart rate findings are reflective of stress reactivity, and our muscle activity findings are reflective of motor processes, we expected cortisol results to mirror our heart rate findings. We also attempted to increase the potency of our stress manipulation by increasing social evaluation – participants were recruited for this experiment in pairs and observed each other putt and lose (for every missed putt) some of their partner's money. Crucially, we also made participants aware of the final high-stress condition at the very start of this experiment, thereby providing maximum advanced warning. This contrasts with our previous experiment, where participants were only informed of the final high-stress putt one minute prior to they were required to complete it. Our rationale here was to provide individuals with more opportunity to prepare for the stressor (Manley et al., 2017). Making this modification also allowed us to revisit our hypothesis regarding phasic heart rate change from our previous experiment. In brief, we failed to support our prediction that phasic heart rate deceleration, a reliable index of preparation for action during golf putting (Cooke, 2013), would be more consistent across low-stress and high-stress conditions among punishment sensitive and reward insensitive individuals. However, insufficient advanced warning about the high-stress condition in that experiment could explain our finding. Manley et al. (2017) reported that punishment sensitive individuals only displayed adaptive preparatory routines preceding stressors when afforded enough time to prepare for the stressor (Manley et al., 2017). In the current study participants had the entire first phase of the experiment (briefing, questionnaires, 45 putts; around two hours) to mentally prepare for the final high-stress putt, thereby providing another opportunity to test our phasic heart rate hypothesis.

The Present Experiment

Building on the work presented in Chapter 2, this experiment was designed to shed further light on the psychophysiological mechanisms that could underpin the relationship between personality and mentally tough behaviour. We retained some of our hypotheses from our previous experiment and modified others based on our Chapter 2 results.

Heart rate reactivity. Following the theorizing of Hardy et al. (2014), and based on our findings from Chapter 2, we expected that when reward sensitivity was low, increases in punishment sensitivity would be associated with decreased heart rate reactivity. Based on our findings from Chapter 2, we further hypothesised that when reward sensitivity was high, decreases in punishment sensitivity would be associated with decreased heart rate reactivity.

Muscular reactivity. Since any effects of stress on muscle activity may have been washed out by motor demands during our task, we revised our predictions regarding muscle activity. Based on our findings from Chapter 2, we expected that when reward sensitivity was low, increases in punishment sensitivity would be associated with increased muscular reactivity at the time of putter-to-ball impact. We also expected that when reward sensitivity was high, decreases in punishment sensitivity would also be associated with increased muscular reactivity at the time of putter-to-ball impact.

Cortisol Reactivity. Our hypotheses for cortisol reactivity mirror our hypotheses for heart rate reactivity. Since increased cortisol is considered a purer measure of stress reactivity than increased heart rate (e.g., increased heart rate could reflect increased effort instead of stress), such findings would increase confidence in our interpretation of our heart rate reactivity data as reflecting changes in stress rather than changes in other psychological processes (e.g., effort).

Phasic heart rate deceleration. We retain our prediction from Chapter 2 for this variable. Specifically, we expected that when reward sensitivity was low, increases in punishment sensitivity would be associated with more consistent phasic heart rate deceleration across the stress conditions.

Movement kinematics. Based on our findings from Chapter 2, we expected that when reward sensitivity was low, increases in punishment sensitivity would be associated with more consistent movement kinematics across the stress conditions. We also expected that when reward sensitivity was high, decreases in punishment sensitivity would be associated with more consistent movement kinematics across the stress conditions.

Correlation Analyses. Finally, for completeness and consistency with Chapter 2, we also assessed correlations between quantitative measures of self-reported mental toughness and the stress-induced changes in each of our performance, psychophysiological and kinematic variables. The results of Chapter 2 did little to endorse the utility of self-report measures of mental toughness. However, due to the potential for a higher level of stress to be manipulated in the current study, we tentatively expected to find significant correlations between the self-report and objective measures to emerge in this experiment.

Method

Participants

One hundred and four (66 male M_{age}= 21.87, *SD*= 2.87, and 38 female, M_{age}= 22.26, *SD*= 3.48) volunteers took part in this study. Power analyses indicated that a sample of 104 would be sensitive enough to detect small-to-medium size effects via linear regression analyses containing three predictor variables (i.e., punishment sensitivity, reward sensitivity, and their interaction term). Accordingly, our study was powered to detect interaction effects of similar magnitude to those revealed by Hardy et al., (2014). All participants were right-handed, novice golfers (i.e., no formal golf handicap) and between the ages 18-40. Participants were scheduled to attend the experiment in same-sex pairs. All participants provided informed consent, and the University Ethics Committee approved the study.

Task

The study consisted of a golf-putting task in which participants used a KT25 Persimmon golf club to putt a Slazenger Raw Distance 432 dimple pattern golf ball 2.5 meters to a standard golf hole, on a Huxley premier Returf Putting green.

Design

We adopted a within-participant design. The first within-participant factor was condition. There was a low-stress condition and a high-stress condition. The low-stress condition was comprised of 5 practice putts for each of the participants. The high-stress condition was comprised of 1 putt for each of the participants, which determined if they and their partner would double, keep, or lose their previous earnings (more details provided in Stress Manipulation section below). The second within-subject factor was epoch. An epoch is the amount of time before the movement when the psychophysiological variables are examined. To examine phasic changes heart rate and muscle activity were analyzed in 13 epochs (i.e., -6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) around putter-to-ball contact (Moore, Vine, Cooke, Ring & Wilson, 2012; Neumann & Thomas, 2011).

Stress Manipulation

The study was designed to induce anxiety akin to what athletes normally experience during competition. At the start of the experiment, each pair of participants was shown a pot of money (£60), told that they would attempt 30 putts each, and told that £1 would be deducted from their £60 prize pot for each putt that was missed. They were also told that when they had both completed their 30 putts, the total money remaining in their prize pot would be confirmed, and then they would have one final putt each. Importantly, to earn the money in their prize pot, one of the participants had to hole their final putt. If both participants holed the final putt, they would earn *double the money* in their prize pot. If neither participant holed the final putt, they would *lose all the money* in their prize pot (i.e., neither participant would be paid). Importantly, both participants were present for all phases of the experiment and observed each other putt to maximize social pressure and ensure each participant was clearly identifiable for any missed putt. The final putt to double, keep or lose earnings was considered the high-stress condition. The low-stress condition was comprised of a 5-putt practice phase that occurred after the initial 30 putts and immediately before the final high-stress putt. No money was won or lost in the low-stress condition.

Self-Report Measures

State Anxiety Manipulation Check

Mental Readiness Form-Likert (MRF-L, Krane, 1994). The MRF-L was used to assess competitive state anxiety. The MRF-L was designed as a short form of the Competitive State Anxiety Inventory (CSAI-2; Martens, Burton, Vealey, Bump & Smith, 1990). Participants used an 11-point Likert scale to rate their cognitive anxiety (1= calm, 11= worried) and their somatic anxiety (1= relaxed, 11= tense). Krane (1994) reported correlations between the MRF-L and the CSAI-2 of 0.76 for cognitive anxiety and 0.69 for somatic anxiety, supporting the concurrent validity of this measure.

Demand and Resource Evaluations. To increase the measurement rigor of our manipulation check, we also assessed perceived demands and resources with two questions from the cognitive appraisal ratio (Tomaka, Blascovich, Kelsey, & Leitten, 1993). Specifically, participants were asked “How demanding do you expect the upcoming block of putts to be?” and “How able are you to cope with the demands of the upcoming block of putts?” Items are measured on a 6-point Likert scale anchored between 1 (not at all) and 6 (extremely). Evaluation scores are measured by subtracting demands from resources (range: -5 to + 5). A positive score shows a challenge state and a negative score shows a threat state; increased stress (i.e., an effective manipulation) is typically associated with increased demands, decreased resources and a more negative overall score to signify a threat state (e.g., Moore et al., 2012; Tomaka et al., 1997; Zanstra, Johnston, & Rasbash, 2010).

Trait Measures

Reward and Punishment Sensitivity. The EPQR-S (Eysenck, Eysenck, & Barrett, 1985) is a 36-item self-report questionnaire which includes three subscales: extraversion “Does your mood often go up and down”; neuroticism “Do you take much notice of what other people think”; and psychoticism “Are you rather lively”. Participants answered each question by responding with *Yes* or *No*. The EPQR-S scales have displayed good internal consistency (α = 0.77–0.88) and are strongly correlated (r = 0.71–0.96) with longer versions of the Eysenckian personality measure (Francis, Philipchalk, & Brown, 1991). Corr (2001) proposed the following transformations to measure reward and punishment sensitivity: reward sensitivity = (E x 2) + N + P), and punishment sensitivity = (12 – E) + (N x 2) – P), where E = extraversion, N = neuroticism and P = psychoticism. In the current study the internal consistencies were: psychoticism (0.52), extraversion (0.85) and neuroticism (0.79). Scores were therefore free to range from 0 to 48 for reward sensitivity and from –12 to 36 for punishment sensitivity.

Mental Toughness Questionnaire-48 (MTQ48; Clough et al., 2002). The MTQ48 is a 48-item questionnaire which includes four subscales: challenge, commitment, control, and confidence, each containing 12 items. The MTQ48 uses a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Example items include: "Challenge usually brings out the best in me" (Challenge); "I usually find something to motivate me "(Commitment); "I generally feel in control" (Control); "I generally feel that I am a worthwhile person" (Confidence). Crust (2007) reported that the MTQ48 has an overall test-retest coefficient of 0.9 and internal consistencies of Control (0.73), Commitment (0.71), Challenge (0.71) and Confidence (0.80). In the current study the internal consistencies were: Control (0.66), Commitment (0.79), Challenge (0.70) and Confidence (0.84).

Mental Toughness Index (MTI; Gucciardi et al., 2015). The MTI is an eight-item unidimensional questionnaire. Example items include "I believe in my ability to achieve my goals", "I strive for continued success" and "I can find a positive in most situations". They are assessed by a 7-point Likert-scale from 1 (being false 100% of the time) to 7 (being true 100% of the time). The MTI has showed adequate internal reliability (α= 0.86) in the study by Gucciardi et al. (2015). In the current study, the internal consistency was 0.78.

Sport Mental Toughness Questionnaire (SMTQ; Sheard et al., 2009). The SMTQ is a fourteen-item multidimensional questionnaire that includes three subscales: confidence, constancy and control. The questionnaire is assessed on a 4-point Likert scale from 1 (not at all true) to 4 (very true). Sample items from each subscale include, "I have unshakeable confidence in my ability" (Confidence); "I worry about performing poorly" (Control –

reverse scored); "I am committed to completing the tasks I have to do" (Constancy). Sheard et al. (2009) reported good internal consistency (confidence $\alpha = 0.80$; control $\alpha = 0.71$; constancy $\alpha = .74$). In the current study internal consistencies were 0.63 for confidence, 0.61 for constancy and 0.62 for control.

Physiological Measures

Heart rate. Instantaneous heart rate was derived from an electrocardiogram (ECG) obtained using three silver/silver chloride electrodes (BlueSensor, Ambu, St Ives, UK) placed on the participant's right collarbone, left collarbone and lowest left rib. The ECG signal was filtered (1-100 Hz; Bagnoli-4, Delsys, Boston, MA) and digitized at 2500 Hz with 16-bit resolution (Power 1401, Cambridge Electronic Design, Cambridge, UK).

Muscle activity. Muscle activity was derived from an electromyogram (EMG) measured using differential surface electrodes (DE 2.1, Delsys) affixed to the extensor carpi radialis and the flexor carpi ulnaris of the left arm, and a ground electrode (BlueSensor) on the left collar bone. The position of the electrodes was chosen based on previous research and pilot testing implicating these muscles in the golf putting stroke (Cooke et al., 2010; Cooke, Kavussanu, McIntyre, Boardley, & Ring, 2011). The signal was amplified (Bagnoli-4, Delsys), filtered (20-450 Hz) and digitized at 2500 Hz with 16-bit resolution (Power 1401), and captured by a computer running Spike2 software.

Cortisol. Cortisol was derived from saliva samples obtained from 5-mins of passive drool into a sterile plastic container. Since cortisol has been shown to peak in the 15-mins after performing a discrete high-stress task (Quested et al., 2011) the high-stress saliva measure was obtained after both participants had completed their high-stress putt. To control for time of day effects on cortisol, the low-stress saliva sample was obtained on a second visit to the laboratory 24-hours after the high-stress saliva sample was obtained. Participants were told to refrain from consuming food and fluid for the 15-mins preceding saliva collection.

Saliva was weighed to the nearest mg and volume was calculated assuming a saliva density of 1.00 g/mL (Cole, Easto, McGivan, Hayes & Smillie, 1988). Samples were then frozen at -80^{0}C until analysis.

Movement Kinematics

A 12-camera reflective motion capture system (Nexus, Vicon, Oxford, UK) was used to measure the kinematics of the golf club and ball. Retro-reflective tape was placed on the ball, and retro-reflective markers (14mm, Vicon) were placed on the heal and the toe of the putter face, and at the base of the putter shaft. Their 3-dimensional positions (i.e., X, Y and Z axes) were recorded at a sample rate of 100 Hz by the motion capture cameras. We extracted five movement kinematic measures from these recordings. Backswing time (ms) and forward swing time (ms) were computed to assess the tempo of the swing. The impact velocity of the clubhead on the primary back-and-forth axis (mm per sec) and the peak velocity of the ball (mm per sec) were computed to assess the impact force of the swing and the resultant ball speed. Finally, the angle of the clubhead at impact (degrees) was computed to assess any angular rotation that may result in putts being pushed or pulled wide of the target. The five-putts in the low-stress condition were averaged to yield a single score for each error measure.

Performance Measures

Four performance errors -- radial (cm), distance (cm), direction (cm) and angle (degrees) – were computed for each putt in the low-stress and high-stress conditions using the motion analysis camera system. Radial error represented the distance between the end position of the ball and the middle of the hole. Distance error represented the difference between the end distance of the ball from the start point, and the distance between the start point and the hole. Direction error represented the end distance left or right that the ball finished from a straight line between the start point and the hole. Angle error represented the angle between the end position of the ball and a straight line between the start point and the hole, with the start point as a reference. The five-putts in the low-stress condition were averaged to yield a single score for each error measure. We also calculated the total percentage of putts holed in the stress condition.

Procedure

At the start of each testing session, each participant was briefed on the procedure and gave written consent on performing in the experiment. Then each participant completed the EPQR-S (Eysenck et al., 1985), the MTI (Gucciardi et al., 2015), the MTQ48 (Clough et al., 2002), and the SMTQ (Sheard et al., 2009). The questionnaires were provided to each participant in a random order.

After questionnaire completion, participants were instrumented for physiological recordings. All the electrode locations on the participants' body were exfoliated and degreased using Nuprep gel and alcohol wipes prior to the electrodes being affixed. Next, we gave participants the putter and they took turns to complete 10 familiarization putts each. Participants were then reminded that in the next phase of the experiment they would complete 30 putts each, and every putt that was missed would cause £1 to be deducted from their £60 starting prize pot. Each participant then completed 2 x 15 putt blocks each in a balanced order (i.e., B, A, B, A). At all times the member of the pair who was not putting was seated in a prominent position and observed all their partner's putts. Upon completion of this initial phase of the experiment, participants were told the final prize fund (i.e., the money remaining in their prize pot) and reminded that they would shortly have the opportunity to earn, lose, or double that money with one final putt each. Prior to the final putt (i.e., the high-stress condition), participants were told they were to have 5-practice putts each, where no money was to be won or lost (i.e., the low-stress condition). Participants completed the MRF-L and rated their demands and resources immediately before the 5-practice putts (low-stress condition) and the final putt (high-stress condition). On completion of the final putt, the equipment was collected, and the participants provided their high-stress saliva sample. We then reminded participants that they should return at the same time on the following day to provide a low-stress saliva sample. They were also told that any money they had won would be paid to them after they returned and provided the second saliva measure. On completion of this second visit participants were paid the earnings he or she had totaled in the event that the final putt was holed, and all participants were thanked for their time. The total laboratory time commitment for both sessions was approximately 2.5 hours per pair (2 hours 15 mins for the main visit, and 15 mins for the second visit to provide the low stress saliva sample).

Data reduction

Individual trials within the continuous physiological recordings were identified using an optical sensor (S51-PA C10PK, Datasensor, Monte San Pietro, Italy), which detected the initiation of putts, and a microphone (NT1, Rode, Silverwater, Australia) connected to a mixing desk (Club 2000, Studiomaster, Leighton Buzzard, UK). Similar to previous studies (Cooke et al., 2014; Neumann & Thomas, 2011), we used the ECG and EMG signals to analyze heart rate and muscle activity in successive 500ms epochs during the 6 s before putter-to-ball impact (i.e., -6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s). Heart rate was calculated from the intervals between the R-waves of the ECG, with the nearest inter-beat-interval to each epoch being used to indicate the instantaneous heart rate for that epoch. Muscle activity was calculated by rectifying the EMG signal and averaging over 500ms windows, such that the mean activity between 6.25 and 5.75 seconds prior to impact was taken to indicate muscle activity 6 s before impact, and so on. These analyses were performed offline using Spike2 software.

Individual trials within the continuous motion analysis recordings were identified manually based on the ball being located on the start point, and the markers on the putter being stationary and immediately behind the ball. Finally, cortisol was analyzed by defrosting the saliva samples and centrifuging samples at 9400 rpm for 10 mins. The samples were then subjected to a commercially available enzyme-linked immunosorbent assay (Salimetrics, State College, PA) to extract cortisol levels.

Statistical Analyses

Our state anxiety manipulation check, the performance measures, the kinematic measures and cortisol were analyzed by paired samples t-tests with stress condition (low, high) as the within-participant factor. Heart rate and muscle activity were analyzed by 2 Stress Condition (i.e., low, high) × 13 Epoch (i.e., -6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) ANOVAs. Significant effects were probed by polynomial trend analyses and planned post-hoc comparisons to compare the magnitude of any -6 s to 0 s changes in the physiological measures. Moderated Hierarchical Regression via PROCESS (Hayes, 2013) was used to examine the interactive effects of punishment and reward sensitivity on heart rate, muscle activity, movement kinematics, cortisol and performance. These analyses are outlined in the results section. Finally, we performed correlation analyses to examine the putative relationships between quantitative MT measures (i.e., MTQ-48, SMTQ-14, and MTI) and our candidate psychophysiological, kinematic and performance indices of MT behavior.

Results

Stress Manipulation Check

The results of paired samples t-tests comparing anxiety, perceived demands and resources, and the challenge-threat index in the low and high-stress conditions are summarized in Table 1. As expected, cognitive state anxiety, somatic state anxiety and perceived demands significantly increased from the low-stress to the high-stress condition. Meanwhile, perceived resources significantly decreased from the low-stress to the high-stress condition, resulting in a significant shift from a challenge appraisal (low-stress condition) to a threat appraisal (high-stress condition). These results confirm that our stress manipulation was successful.

Table 1. Anxiety, Self-confidence and Challenge/Threat appraisals in the Low-Stress and High-Stress conditions

	Condition		
Measure	Low-Stress	High-Stress	
	Mean (SD)	Mean (SD)	
Cognitive anxiety	5.12 (2.69)	6.64 (2.79)	t(103) -6.39***
Somatic anxiety	5.26 (2.45)	6.19 (2.59)	t(103) -4.16***
Demands	3.91 (1.42)	4.63 (1.43)	t(103) -5.77***
Resources	4.04 (1.14)	3.75 (1.32)	t(103) 3.12 **
Challenge & Threat Index	0.13 (2.12)	-0.87 (2.16)	t(103) 6.06 ***

**$p < .01$ ***$p < .001$

Heart rate

Due to excessive artefacts, the electrocardiogram for one participant was unscoreable, leaving a sample of 103 for heart rate analyses. The result of a 2 stress (low vs. high) × 13 Epoch (-6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) ANOVA computed on heart rate is depicted in Figure 1 .There were main effects for stress, F (1, 102) = 85.91, $p < .001$, $\eta_p^2 = .45$, and epoch $F(12, 1224) = 13.91$, $p < .001$, $\eta_p^2 = .12$. In the high-stress condition heart rate was significantly faster (M = 98.18, SD = 17.5bpm) than in the low-stress condition (M = 88.45, SD = 15.1bpm). The effect of epoch was best characterized by a linear polynomial trend ($p < .001$, $\eta_p^2 = .17$) showing a progressive decrease in heart rate (i.e., heart rate deceleration) during the six-seconds prior to impact (Figure 1). Importantly, there was also a Stress × Epoch interaction F (12, 1224) = 5.12, p <. 01, $\eta_p^2 = .05$, reflecting a difference in the rate of heart rate deceleration between the two stress conditions. Specifically, paired-samples t-tests (heart rate at the -6s epoch paired with heart rate at the 0s epoch) performed separately for each condition revealed a strong and significant heart rate deceleration in the low-stress condition ($M_{\text{heart rate -6 epoch}}$ = 90.41, SD = 14.91, $M_{\text{heart rate 0 epoch}}$ = 85.65, SD = 15.09, $t(103) = 7.93$, $p < .001$), and a modest and non-significant heart rate deceleration in the high-stress condition ($M_{\text{heart rate -6 epoch}}$ = 98.61, SD = 17.72, $M_{\text{heart rate 0 epoch}}$ = 97.61, SD = 18.02, $t(103) = 1.08$, $p = .28$).

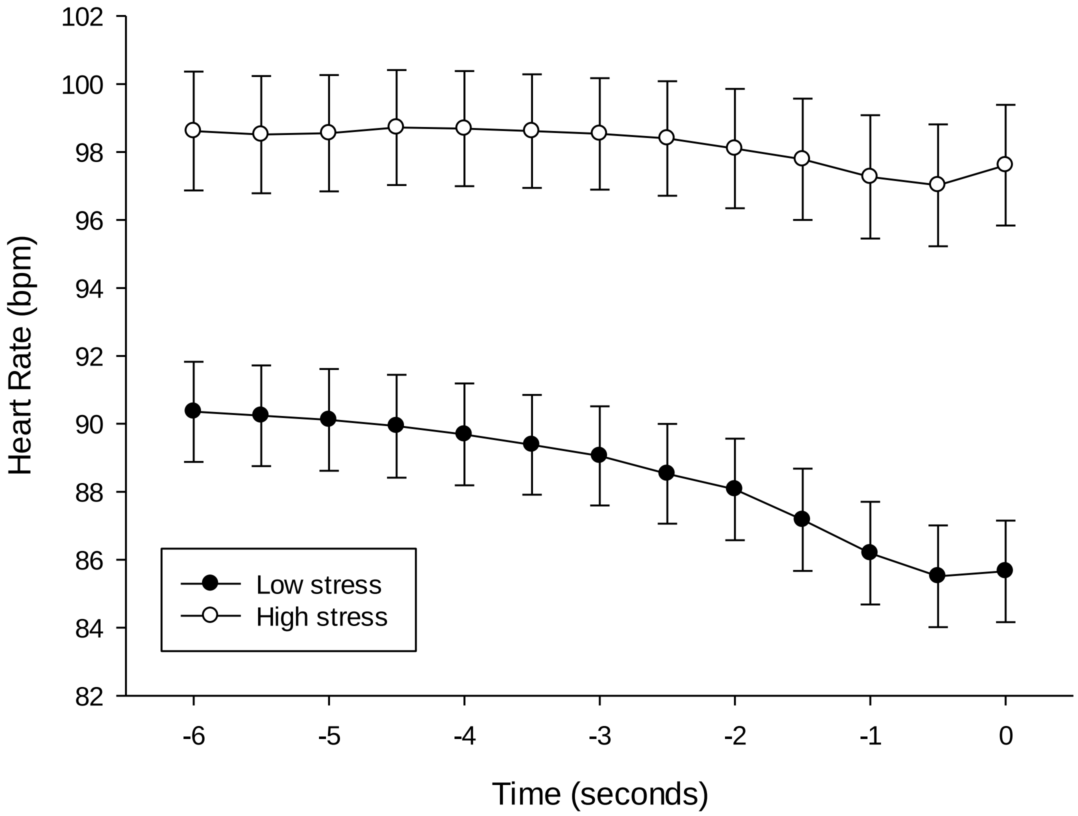

Figure 1. Heart rate Stress × Epoch interaction. Error bars indicate standard error of the means.

Muscle activity

The result of a 2 Stress (low vs. high) × 13 Epoch (-6 s, -5.5 s, -5 s, - 4.5 s, -4 s, -3.5 s, -3 s, -2.5 s, -2 s, -1.5 s, -1 s, -0.5 s, 0.0 s) ANOVA computed on extensor muscle activity is depicted in Figure 2. There was no main effect for stress condition $F(1, 103) = 0.08$, $p = .77$,

η_p^2 = .001, however there was a significant main effect for epoch, *F* (12, 1236) = 31.20, $p <$ .001, η_p^2 = .23. The effect of epoch was best characterized by a quadratic polynomial trend (p < .001, η_p^2 = .30) showing an initially low and stable extensor muscle activity (-6 s to -1.5 s), followed by a sharp increase in extensor muscle activity during the final 1.5 s before impact (Figure 2). There was no epoch × stress interaction *F* (12, 1236) = 1.14, *p* = .33, η_p^2 = .01.

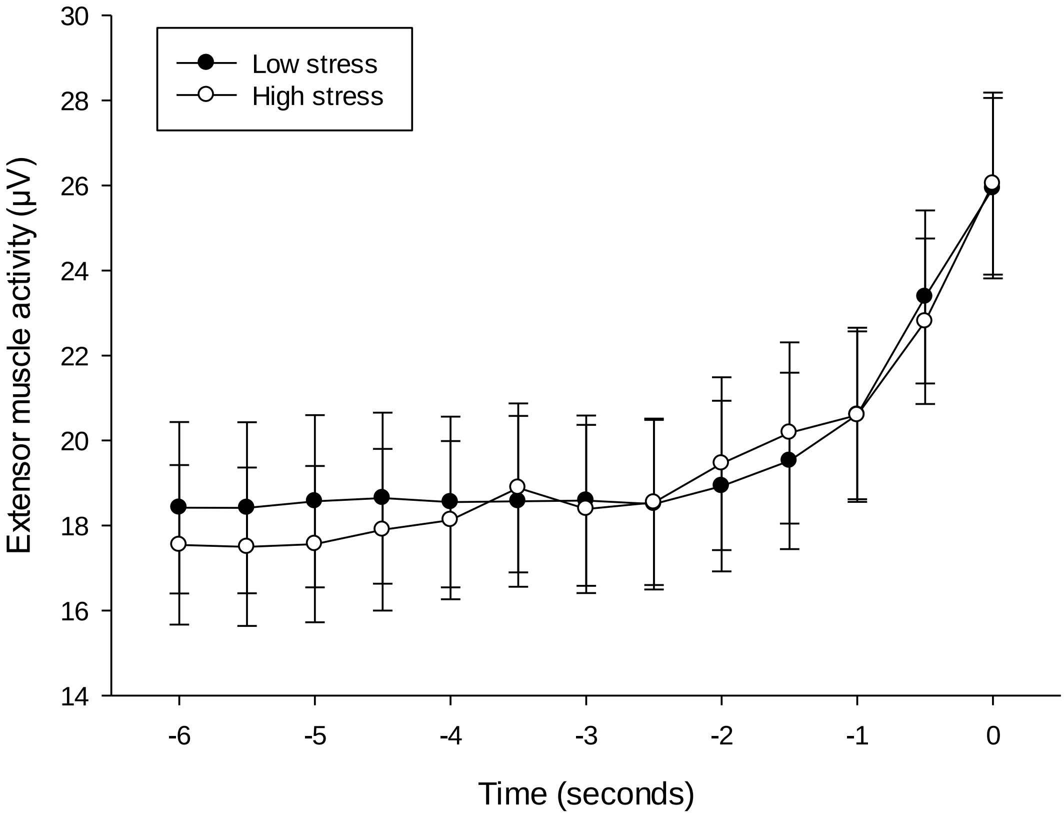

Figure 2. Extensor muscle activity Stress × Epoch interaction (ns). Error bars indicate standard error of the means.

For flexor muscle activity, there was no significant main effect for stress, *F* (1, 103) = 2.77, *p* = .10, η_p^2 = .02. However, there was a significant main effect for epoch, *F* (12, 1236) = 22.480, $p < .001$, η_p^2 = .18. The effect epoch was best characterized by a quadratic polynomial trend ($p < .001$, η_p^2 = .35) showing an initially low and stable flexor muscle activity (-6 s to -1.5 s), followed by a sharp increase in flexor muscle activity during the final

1.5 s before impact (Figure 3). There was no epoch × stress interaction F (12, 1236) = 0.62, p = .55, η_p^2 = .01.

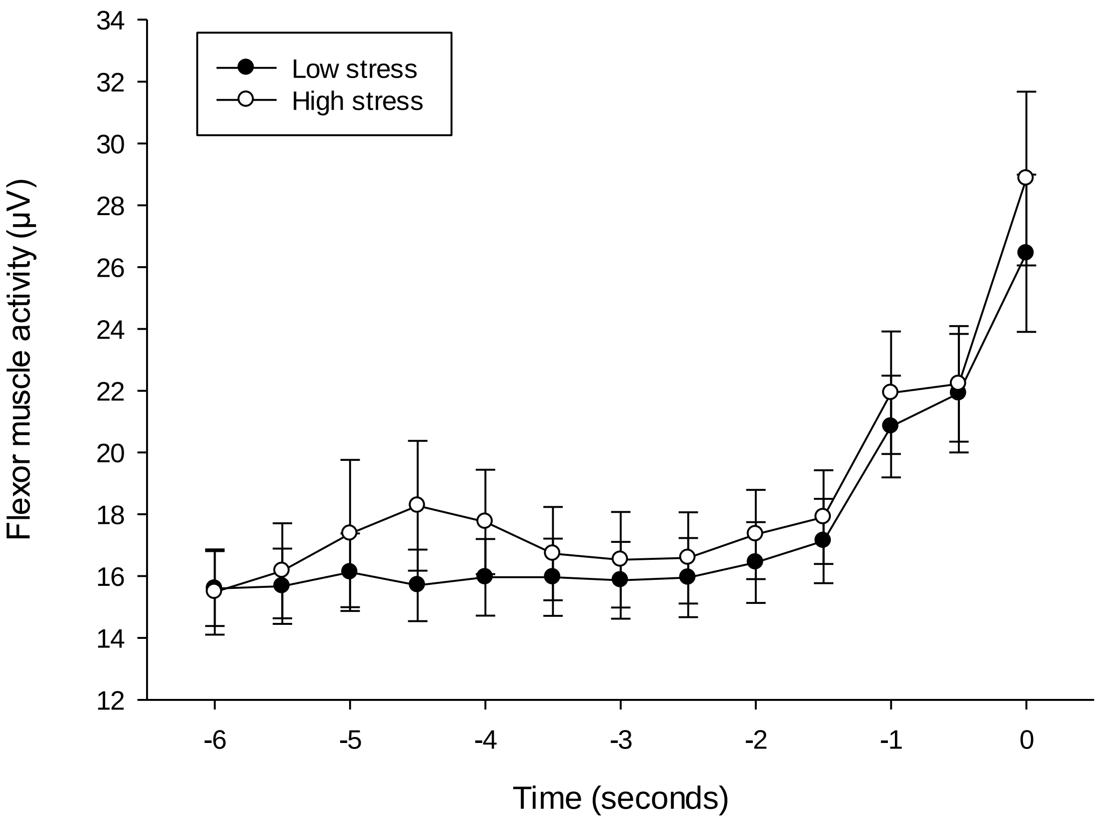

Figure 3. Flexor muscle activity. Error bars indicate standard error of the means.

Cortisol

One participant failed to attend the low-stress saliva collection session, therefore, only 103 participants had full saliva samples for analysis. The paired samples t-test comparing cortisol after the final putt (high-stress condition) with cortisol 24-hours later (control visit, low-stress condition) revealed a significant difference whereby cortisol surprisingly increased from high-stress (M = 5.53, SD = 2.79 mmol/l) to low-stress (M = 7.11, SD = 4.39 mmol/l), t (103) = -3.66, p < .001. Possible explanations for this unexpected finding are considered in the discussion.

Performance

The results of paired samples t-tests conducted on our four measures of performance error are detailed in Table 2. In brief, there were modest increases in direction and angular error from the low-stress condition to the high-stress condition, indicating that putts were more likely to finish wide of the hole in the high-stress condition. However, the induction of stress had no effect on distance control, and no significant effect on our composite measure of mean radial error. Finally, analyses of our crudest measure of performance (total percentage of putts holed) revealed that 192 out of the 520 total putts struck in the low-stress condition went in the hole (i.e., 36.9% holed) while 45 out of the 104 participants holed their putt in the high-stress condition (i.e., 43.2% holed).

Table 2. Performance in the Low-Stress and High-Stress conditions

	Condition		
Measure	Low-Stress	High-Stress	
	Mean (SD)	Mean (SD)	
Mean Radial Error (cm)	41.49 (18.02)	41.75 (38.80)	t(103) -0.07
Distance Error (cm)	33.92 (19.35)	39.16 (39.04)	t(103) -1.42
Direction Error (cm)	6.55 (7.02)	8.85 (10.67)	t(103) -1.91†
Angle Error (degrees)	1.25 (1.32)	1.74 (2.06)	t(103) -2.08*

**p* < .05, †*p* = .06

Movement kinematics

The results of paired samples t-tests comparing movement kinematic measures in the low and high-stress conditions are summarized in Table 3. In brief, there was a significant increase in clubhead angle at impact from the low-stress condition to the high-stress condition. This indicates that the ball was struck with a clubhead impact angle that was more likely to send the ball off line during the high-stress condition. This effect is compatible with the performance error results and can explain why more putts finished wide of the hole in the high-stress condition. However, stress had no significant effects on timing or velocity elements of the swing.

Table 3. Movement kinematics in the Low-Stress and High-Stress conditions

	Condition		
Measure	Low-Stress Mean (SD)	High-Stress Mean (SD)	
Backswing time	646.90 (251.40)	640.37 (236.26)	t(103) .236
Forward swing time	322.16 (82.99)	327.20 (98.23)	t(103) -.792
Peak ball velocity (mm/sec)	2194.51 (168.14)	2220.59 (289.23)	t(103) -1.05
Impact velocity (mm/sec)	1292.06 (99.10)	1299.60 (180.78)	t(103) -.491
Clubhead angle at impact (degrees)	2.21 (1.62)	2.85 (2.09)	t(103) -3.29**

***p*<.01

Effects of Personality on Heart Rate, Muscle Activity, Performance and Movement Kinematics

To examine the hypothesised interactions, we used moderated hierarchical regression via PROCESS (Hayes, 2013). PROCESS allows moderation analyses to be conducted without manually creating the product term for the interaction. PROCESS also provides results of simple slope analysis to interpret any significant interactions (Cohen, Cohen, West, & Aiken, 2003). All data were subject to z-score transformation before analysis (Jaccard & Turrisi, 2003). Simple slopes were analysed and plotted at Mean ± *1SD*. Lower and upper bound 95% confidence intervals (CI) that do not encompass zero indicate significance at the .05 level. Alpha was set at .05 for all analyses.

Moderated Hierarchical Regression Analysis was used to examine the interactive effects of punishment and reward sensitivity on changes in heart rate, muscle activity (extensor, flexor), performance, and movement kinematics from the low-stress to the high-stress condition. In all subsequent analyses punishment sensitivity was entered as the predictor variable and reward sensitivity as the moderator variable. The dependent variable was calculated from subtracting low-stress condition scores from the high-stress condition scores for heart rate, muscle activity, and each performance and kinematic measure. These analyses thereby probed the extent to which personality can predict stress-reactivity. For heart rate, we also computed the difference in heart rate change from the -6 s to the 0 s epoch for each stress condition and performed the regression analyses on this additional dependent variable. This latter analysis thereby probed the extent to which personality can predict stress-induce changes to physiological indices of motor preparation.

Heart rate. To examine the effect of personality on heart rate reactivity to stress, we conducted moderated herarichal regression analyses using punishment sensitivity, reward sensitivity, and the punishment × reward sensitivity interaction term for all 13 epochs. There were no main effects of punishment or reward at any of the epochs. Significant interactions ($p < .05$) emerged at 3 out of the 13 epochs, but since most epochs indicated non-significant effects, there was no consistent trend. When all epochs were averaged to permit a single representative analysis, there were no significant main effects for reward ($\beta = -0.22$, $p = .84$) or punishment sensitivity ($\beta = -1.17$, $p = .28$), and there was no punishment by reward sensitivity interaction ($\beta = -1.84$, $p = .15$). The interactions that emerged at 3 out of 13 epochs are thus likely to reflect type I errors, and will not be considered further.

To examine the effect of personality on the rate of phasic heart rate change across epochs, we conducted an identical analysis to predict the difference in the rate of change in heart rate from -6 s to 0 s between the low-stress and the high-stress condition. This analysis revealed no significant main effects for reward (β = -1.38, p = .17) or punishment sensitivity (β = -.30, p = .76), However there was a significant reward by punishment interaction (β = 2.34, p < .05). The interaction shows that when reward sensitivity is low, as punishment sensitivity increased, there was a preparatory deceleration in heart rate (i.e., less perturbation of pre-performance routine) across low-stress and high-stress conditions. The simple slopes analysis was not significant (β = -1.00, p = .15, 95% CI [-4.88, .780]). However, the opposite relationship was evident when reward sensitivity was high; the stress-induced attenuation of phasic heart rate deceleration was greater as punishment sensitivity increased. The simple slopes analysis was not significant (β = 1.00, p = .10, 95% CI [-.54, 5.87]).

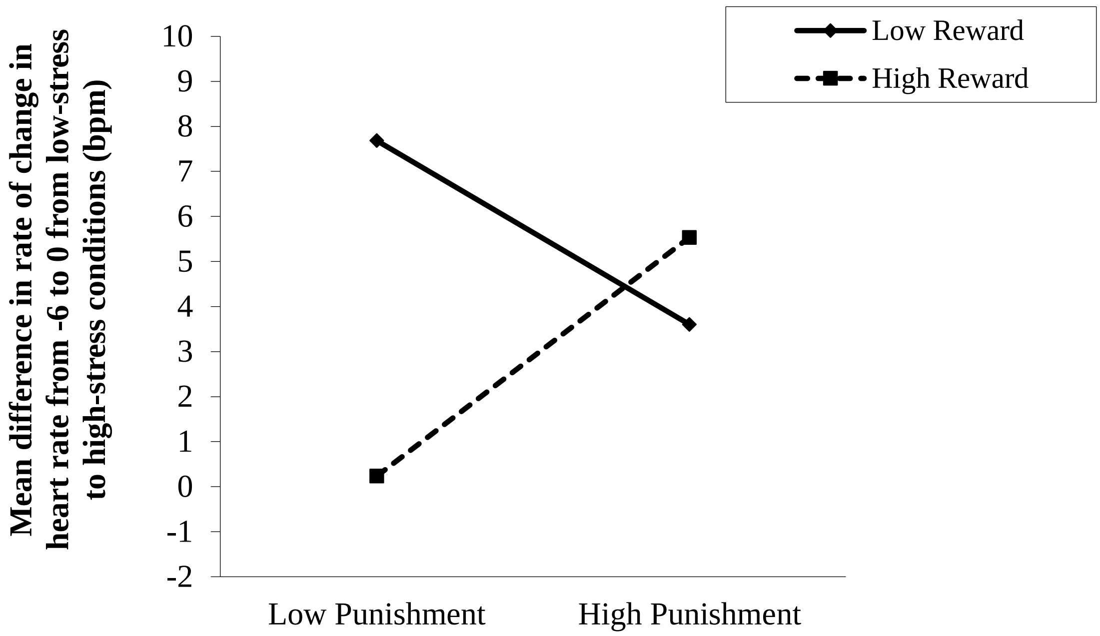

Figure 4. Interaction between punishment sensitivity and reward sensitivity predicting phasic heart rate change from low-stress to high-stress condition

Thus, personality was able to predict the changes in heart rate across time, an index of motor programming / preparation, but could not predict the extent of the observed stress-induced increase in heart rate, a tentative index of arousal/emotion/motivation.

Extensor Muscle Activity. Moderated hierarchical regression analyses (in similar fashion to above) were conducted for each of the 13 epochs. There was a main effect for reward sensitivity at 1 out of the 13 epochs, but there were no main effects of punishment and no reward × punishment interactions. When all epochs were avaraged to permit a single representitive analyses, there were no significant main effects for reward (β = -0.36, p = .68) or punishment sensitivity (β = -0.20, p = .82), and there was no punishment by reward sensitivity interaction (β = -0.39, p = .70). The main effect for reward that emerged at 1 out of 13 epochs is thus likely to reflect type I errors and will not be considered further.

Flexor Muscle Activity. Moderated hierarchal regression analysis was conducted for each of the 13 epochs. There was a main effect for reward sensitivity at 2 out of the 13 epochs, but there were no main effects of punishment and no reward × punishment interactions. When all epochs were avaraged to permit a single representitive analyses, there were no significant main effects for reward (β = 0.68, p = .31) or punishment sensitivity (β = 0.21, p = .75), and there was no punishment by reward sensitivity interaction (β = 0.23, p = .76). The main effects for reward that emerged at 2 out of 13 epochs are thus likely to reflect type I errors and will not be considered further.

Cortisol. Since the expected stress-induced cortisol reactivity pattern (i.e., significantly higher cortisol in the high-stress condition) did not manifest (cortisol actually changed in the opposite direction) we were unable to test our hypothesis that relative sensitivity to punishment and insensitivity to reward would be associated with reduced cortisol reactivity to stress. Instead, we conducted exploratory moderated hierarchical regression analyses to see if personality could predict absolute levels of cortisol in the high-stress condition only. No significant main or interaction effects emerged.

Performance. Moderated hierarchical regression analyses were conducted to see if personality could predict the condition differences in performance. Results revealed a significant main effect of reward sensitivity on distance error (β = 95.21, $p < .05$), and a punishment × reward sensitivity interaction that approached significance for angular error (β = 0.52, $p < .067$). This indicated that when reward sensitivity was low, as punishment sensitivity increases, the stress-induced change in angular error was smaller. The simple slopes analysis was not significant (β = -1.00, $p = .29$, 95% CI [-1.04, .317]). However, the opposite relationship was evident when reward sensitivity was high; the change in angular error was reduced as punishment sensitivity decreased. The simple slopes analysis was not significant (β = 1.00, $p = .09$, 95% CI [-.11, 1.44]).

No other effects were significant.

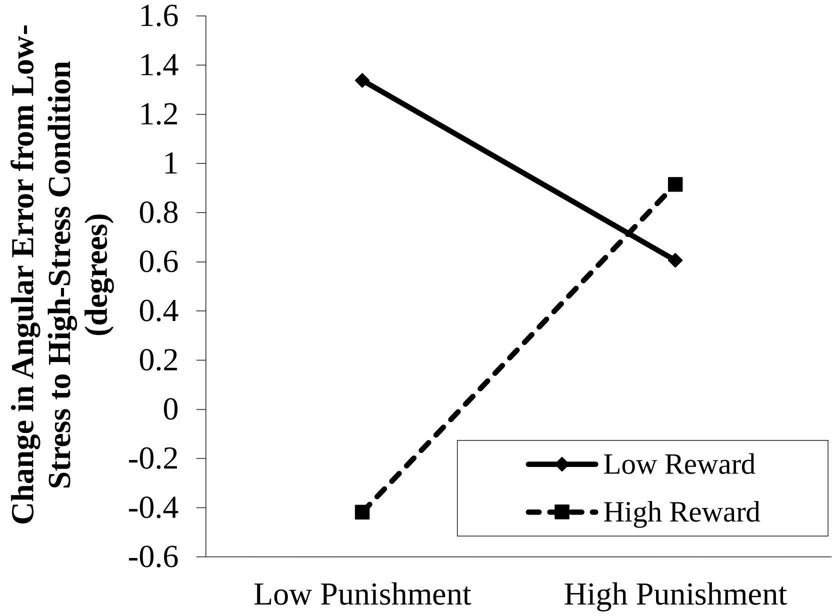

Figure 5. Interaction between punishment sensitivity and reward sensitivity predicting change in angular error from low-stress to high-stress condition

Kinematics. Moderated hierarchical regression analyses were conducted to see if personality could predict the condition differences in movement kinematics. However, results revealed no significant main effects or interactions for any of the kinematic variables.

Relationships between quantitative measures of MT and psychophysiological, kinematic and performance measures.

The mean for each of the personality and self-reported MT measure is reported in Table 4.

Table 4. Mean and standard deviation of personality and mental toughness self-reports

Measure	Mean	SD
Punishment	25.10	6.81
Reward	9.47	8.57
Mental toughness -48 (Challenge)	3.77	.51
Mental toughness -48 (Commitment)	3.60	.60
Mental toughness -48 (Control)	3.36	.52
Mental toughness -48 (Confidence)	3.47	.46
Sport mental toughness questionnaire (Confidence)	2.88	.51
Sport mental toughness questionnaire (Constancy)	2.99	.40
Sport mental toughness questionnaire (Control)	2.63	.59
Mental toughness index	5.44	.72

Correlation analyses assessed the relationships between quantitative measures of MT and our proposed psychophysiological, kinematic and performance indices of MT behaviour. In total, 112 possible correlations were assessed (i.e., 4 subscales from MTQ-48, 3 subscales from SMTQ-14, the single subscale MTI × 14 psychophysiological, kinematic and performance outcome measures). Results revealed that out of a possible 112 correlations, only 6 correlations were significant. Specifically, the control and confidence subscales of the SMTQ-48 and the challenge subscale of the MTQ-48 all displayed small and positive correlations (r's = .20, p's < .05) with heart rate reactivity from low- to high-stress conditions. The commitment subscale of the MTQ-48 displayed a small and negative correlation (r = -.20, $p < .05$) with the change in angular error from low- to high-stress conditions. Finally, the MTI-8 displayed a small and positive correlation (r = .19, $p < .05$) with the change in peak ball velocity and a small and negative correlation (r = -.22, $p < .05$) with the change in clubhead angle from the low- to high-stress condition. Given the number of correlation analyses performed, the normal distribution curve would expect up to six correlations (i.e., 5% of 112) to emerge by chance. Since the total number of significant correlations did not exceed the number expected by chance, our data provide little evidence to endorse quantitative MT measures as reliable predictors of process and outcome variables associated with MT behaviour.

Discussion

The aim of the current study was to replicate and extend the findings from Chapter 1 and to further provide clarity regarding the work of Hardy et al. (2014), which examined the interactive effects of punishment and reward sensitivity on athletes mentally tough behaviour under pressure. Across two studies, Hardy et al. found that when reward sensitivity was low, increasing levels of punishment sensitivity was related to an increase in mentally tough behaviour. When reward sensitivity was high, increasing levels of punishment sensitivity related to lower levels of mentally tough behaviour. We followed Hardy et al.'s recommendation that research should focus on the cognitive neuroscience behind mentally tough behaviour by examining appropriate psychophysiological and behavioural markers that may underpin such behaviour. To do this, we examined punishment and reward sensitivity with psychophysiological variables such as hormonal reaction to stress, heart rate reactivity to stress, movement kinematics, muscle activity, and performance. To complement these variables, we also examined a battery of self-report mental toughness questionnaires that should also relate to mentally tough behaviour.

One of the key differences between the present Chapter and Chapter 2 is that we intensified the stress manipulation where every participant faced a loss vs non-loss situation. That is, they were given a set amount of money at the start of testing where they either kept it or lost it depending on their putting performance across time. Stress was further manipulated in that one's own poor performance in the stress manipulation had the potential to carry negative consequence for their putting partner. Further, we provided every participant with early warning about the stress manipulation (e.g., Manley et al., 2017). By doing so, we could further explore the beneficial role that early threat detection coupled with high punishment and low reward personality profiles has upon psychophysiological responses to threat.

Phasic heart rate deceleration

Regarding the manipulation that participants were given early warning of the high-stress condition, a key objective of this study was to re-examine our hypothesis that punishment and reward sensitivities would interact to predict phasic heart rate deceleration, a psychophysiological index of motor preparation (Lacey & Lacey, 1978). Results supported our hypothesis. Specifically, we found that the high-stress condition largely abolished the preparatory heart rate deceleration that preceded putts in the low-stress condition, but the extent to which the preparatory deceleration was disrupted by high-stress depended on personality. That is, when reward sensitivity was low, increasing punishment sensitivity was associated with less stress-induced disruption of the phasic deceleration profile. When reward sensitivity was high, decreasing punishment sensitivity was associated with less stress-induced disruption of the phasic deceleration profile.

Since phasic heart rate deceleration before golf putts is considered to partly reflect the extent to which individuals have prepared their motor response, with greater deceleration indicating better preparation (Cooke, 2014), our findings can be interpreted as supportive of the idea that the combination of sensitivity to punishment and insensitivity to reward with appropriate early threat warning prompts superior preparation for stressors (Hardy et al., 2014; Manley et al., 2017). The reason we did not support this hypothesis in the previous Chapter is likely due to late warning about the stress manipulation in that Chapter. That is, in Chapter 2 participants were only given one minute warning regarding the double or nothing stress putt. In this situation, participants had limited time to process and mentally prepare for the stress laden putt. With around two hours of warning about the stressor in the current Chapter, and five inconsequential practice putts immediately before the high-stress condition, there was much more opportunity for mental preparation, and those who were relatively sensitive to punishment and insensitive to reward seemingly used that opportunity to good effect. These findings are consistent with the results of Manley et al. (2017), who showed that increasing punishment sensitivity was associated with better outcomes under stress only when time to prepare for the stressor was granted.

Interestingly, although the simple slope was not significant, it is worth noting that participants who were highly sensitive to reward and insensitive to punishment displayed a similar stress-resistant heart rate deceleration profile to their punishment sensitive and reward insensitive counterparts. Interactions of a similar nature were identified for many variables in the previous Chapter as well. Accordingly, preparation and optimal psychophysiological reactivity under stress is not reserved purely for those who are sensitive to punishment and insensitive to reward. However, in certain tasks such as the putting task used in this thesis, being sensitive to reward and insensitive to punishment may be just as helpful, perhaps because reward sensitivity motivates individuals to approach a stressor, while punishment insensitivity reduces the chances of those individuals being derailed by distractions or worrisome thoughts. What is clear across both studies is that being highly sensitive (hypersensitivity) or highly insensitivity (hyposensitivity) to both punishment and reward is unlikely to yield mentally tough outcomes.

Heart rate reactivity

For heart rate reactivity, we hypothesised that individuals who are sensitive to punishment and insensitive to reward should display reduced heart rate reactivity to stressors. Overall, heart rate significantly increased by an average of 10 beats per minute from low-stress to high-stress conditions. Interestingly, the highest heart rate reactivity was an increase of 45 beats per minute and the lowest heart rate reactivity was a reduction of 14 beats per minute. However, no interactions were found between reward sensitivity and punishment sensitivity on heart rate reactivity, so we did not support our hypothesis that increasing punishment sensitivity would be associated with reduced heart rate reactivity when reward sensitivity was low. This result contrasts our finding from Chapter 2 and is surprising given that we intensified the strength of our stress manipulation in this study. However, our finding may be attributed to the fact that participants were given much more time to mentally prepare for the stressor in this study compared to Chapter 2. Specifically, although the heart rate reactivity was large in the current study, it is possible that some of the reactivity was driven by excitement rather than stress, since participants are more likely to have felt prepared for the stressor in this study than in Chapter 2. Accordingly, heart rate reactivity may not be a pure measure of stress in designs where lots of warning about the stressor is given.

Cortisol

For cortisol, we hypothesised that individuals who are sensitive to punishment and insensitive to reward should display lower levels of cortisol in the high-stress condition. Unexpectedly, cortisol levels were higher in low-stress condition (control visit one day after the experiment) than in the high-stress condition (day of the experiment). We further examined our cortisol data to probe this unexpected finding by considering the effect of the final putt outcome on cortisol responses. These control analyses (reported in the appendices) revealed that the increase in cortisol from the high-stress condition to the low-stress condition was driven by pairs of participants who holed either one (keep money) or both (double money) of their putts in the high-stress condition. Those who missed both putts (lost money) did not increase their cortisol from the experiment to the control visit. Accordingly, it seems likely that the overall increase in cortisol that occurred on the day after the experiment was an anticipatory excitement response associated with receiving a cash prize (since prize money was paid on the control visit). Some support for this reasoning can be drawn from studies assessing cortisol in other sports. For example, in studies of male wrestlers (Elias, 1981) and tennis players (Mazur & Lamb, 1980), post-match cortisol was significantly higher in individuals that won compared to those who lost. Similarly, cortisol has been show to rise in anticipation of receiving other forms of reward, such as food (Ott et al., 2011). In sum, cortisol may be reflective of more than just stress, and in our study it could have increased due to the excitement of receiving a reward during the control visit. In hindsight, it may have been more useful to schedule the low-stress cortisol sampling for the day before rather than the day after the experiment. Future experiments can adopt this design to test our interpretation of the cortisol data.

Since cortisol was not elevated in our high-stress condition we were unable to test our prediction that reward and punishment sensitivity would interact to predict cortisol reactivity to stress. Exploratory analyses revealed that reward and punishment sensitivities did not predict absolute (or reactivity) scores for cortisol. However, this is unsurprising given that cortisol could have been influenced by non-stress factors (e.g., excitement) in our study. Future research adopting more threatening stress manipulations can further examine the relationships between personality, cortisol and resilient performance.

Muscle activity

Our initial theorizing about muscle activity (Chapter 1 & 2) led us to reason that mentally tough behaviour would be reflected by a consistent pattern of muscle activity (i.e., lack of stress-induced perturbation) from low-stress to high-stress conditions. However, the results of the experiment reported in Chapter 2 implied that muscle activity assessed during movement in our task was more reflective of variability in technique than variability in psychological stress. Accordingly, based on our findings from Chapter 2, we revised our predictions and for the current experiment we predicted that when reward sensitivity was low, increases in punishment sensitivity would be associated with increased muscular reactivity at the time of putter-to-ball impact. We also expected that when reward sensitivity was high, decreases in punishment sensitivity would also be associated with increased muscular reactivity at the time of putter-to-ball impact. These were underpinned by previous studies of muscular activity during golf putting, which suggested that greater muscle activity around impact was associated with greater expertise and better technique (Cooke et al., 2014).

Our results failed to support these predictions. Muscle activity reliably increased in the final moments preceding putter-to-ball impact (i.e., during the swing), but this was not influenced by stress, nor was it predicted in any consistent manner by reward or punishment sensitivity. This unexpected finding could also be influenced by the change in stress manipulation from Chapter 2 to Chapter 3. Specifically, while we attempted to intensify our stress manipulation in the current study (and our manipulation checks endorse its effectiveness), it seems that providing early warning of the high-stress condition serves to reduce the likelihood of stress disrupting technique, irrespective of personality. Further evidence to endorse this idea is evident from our performance and movement kinematic findings discussed below. In brief, significant differences as a function of stress condition for muscle activity, movement kinematics and performance measures were widespread in

Chapter 2, where the warning of the stressor was late, but were sparse in the current experiment, where the warning for the stressor was early.

Alternatively, the inconsistent muscle activity results between Chapter 2 and Chapter 3 could indicate that the muscle activity effects that emerged in the previous Chapter were spurious findings. After all, we found that reward and punishment sensitivities interacted to predict muscle activity at only one out of thirteen epochs analysed in Chapter 2. However, we chose to interpret that finding rather than dismissing it as a type I error because the interaction occurred at the crucial putter-to-ball contact epoch, and was consistent with club-head kinematic data, leading us to believe that the effect was meaningful. Further studies of the relationship between personality, muscle activity, and performance, as a function of early and late stressors are required to shed further light on this issue.

Performance

For performance, we hypothesised that individuals who are sensitive to punishment and insensitive to reward should produce robust performance under stress. The overall effects of stress on performance in this study were mild, with no significant changes distance or mean radial error from the low-stress condition to the high-stress condition. There was some evidence that stress had an adverse effect on direction, with a trend for increased direction error, and a significant increase in angular error from the low-stress to the high-stress condition. However, the impact of this finding was somewhat offset by the fact that, in absolute terms, slightly more putts were successfully holed in the high-stress than in the low-stress condition. In other words, although direction and angular error appeared to increase, they did not change to such an extent to affect whether putts were holed or not (short putts can tolerate some imprecision in direction and still be successful due to 10.8 cm diameter of the hole).

More interestingly, and superseding these main effects of stress, we found a trend for punishment and reward sensitivity interacting to predict the stress-induced disruption in angular error. Specifically, when reward sensitivity was low, an increase in punishment sensitivity was associated with a reduction in the extent to which the high-stress condition increased angular error. In other words, relative sensitivity to punishment and insensitivity to reward was associated with an increased likelihood of striking putts on the correct line (i.e., better performance) in the high-stress condition. This finding is consistent with our hypothesis and the finding of Beattie et al. (2017) who also observed better performance in individuals whose punishment sensitivity was high and reward sensitivity was low.

Like many of the interactions reported over the course of this thesis, we also found that when reward sensitivity was high, a decrease in punishment sensitivity was also associated with an increased likelihood of better performance. This adds further evidence to our earlier idea that sensitivity to punishment and insensitivity to reward is not the only personality profile to predict mentally tough outcomes. Similarly, the results depicted in Figure 5 add further evidence that being hyposensitive or hypersensitive to both punishment and reward are the personality profiles least likely to yield mentally tough outcomes.

Movement kinematics

In accord with our findings from Chapter 2, we hypothesised that individuals who are sensitive to punishment and insensitive to reward should display less disruption of movement kinematic variables when transitioning from low- to high-stress. Overall, there were no changes in the backswing time, forward swing, peak ball velocity, and impact velocity from low-stress to high-stress conditions, but stress did have some disruptive effect by increasing clubhead angle at impact in the high-stress condition. These effects are consistent with our performance results and the notion that the induction of stress elicited a slight tendency to alter clubhead angle and strike the ball off-line, albeit not to an extent to have adverse effects on the final outcome (i.e., impact whether the ball was holed or missed).

Given our performance results and our finding that personality predicted clubhead angle at impact in Chapter 2, it is surprising that there were no effects of reward or punishment sensitivities on movement kinematics in the present study. This null finding does not support our hypothesis. Clubhead angle at impact is highly correlated with angular error, but other factors such as swing plane and the position at which the ball impacts the clubface can also influence angular errors of performance beyond the influence of the clubhead angle. The finding that reward and punishment sensitivities interact to predict angle of error, but not clubhead angle at impact, imply that our angle of error findings must have been influenced in part by non-clubhead angle factors in the current study.

The inconsistency of findings between Chapter 2, where personality predicted kinematics, and the current Chapter, where personality is unrelated to kinematics, may be attributed to the change in stress manipulation. Specifically, it seems that personality is more predictive of our reactivity and behavior when we are confronted with a late stressor where trait like behaviors would come to the forefront (Chapter 2) than when we are given early warning of a stressor (Chapter 3) where preparation is key (e.g., Manley et al., 2017). This is likely because any innate tendencies that may emerge when a stressor first manifests had the chance to dissipate in this study before the high-stress condition (e.g., initial worries may have been processed and reappraised by the time the high-stress condition materialized).

Self-report MT

We hypothesised that there should be a multitude of significant correlations between self-report assessments mental toughness and our outcome variables. However, the results showed that only 6 correlations out of a possible 112 correlations were significant in the current study (less than would happen by chance alone). These results are consistent with our findings from Chapter 2 and cast further doubt over the utility of self-reported mental toughness measures. However, further interrogation of these measures is encouraged, as the lack of correlations with our speculative psychophysiological and behavioural indices of mental toughness is not enough evidence on its own to cast aside self-report tools. We hope future researchers can co-develop a coherent battery of self-report and objective measures that display strong convergent validity and provide a dedicated multi-measure mental toughness assessment tool.

Conclusion

In conclusion, changing the stress manipulation and giving all participants warning of the nature of the stress manipulation seemed to influence the change of results from Chapter 2 to Chapter 3. For example, punishment and reward sensitivities did not predict heart rate reactivity but instead predicted phasic heart rate deceleration. However, the nature of the interaction was similar across both Chapters suggesting that high levels of reward sensitivity and low levels punishment sensitivity may not be as detrimental as first thought (e.g., Hardy et al., 2014). One common finding across both chapters was the relative lack of significant relationships between self-report mental toughness and our outcome variables. Research has shown that the mental toughness questionnaires used in this thesis have been shown to correlate with coping, affect intensity, hardiness, optimism, positive and negative affect, workplace performance, key outcomes in education and selection testing in the military (Clough et al., 2002; Gucciardi et al., 2015; Sheard et al., 2009). Perhaps such measures are not sensitive enough to detect minor adjustments in closed motor skill tasks or psychophysiological responses to stress.

Chapter 4

General Discussion

Thesis Aims

The body of work reported in this thesis was designed to build on Hardy, Bell and Beattie's (2014) seminal paper investigating the interactive effects of personality traits on mentally tough behaviour. Hardy and colleagues (2014) reasoned that mental toughness should be a relatively stable trait and therefore should be predicted by aspects of personality. They focused especially upon Gray and McNaughton's (2000) revised Reinforcement Sensitivity Theory of personality (rRST) and hypothesized that an individual's sensitivity to punishment and their sensitivity to reward would interact to predict mentally tough behaviors. Across two studies of professional cricketers, their results confirmed that reward and punishment sensitivities interacted to predict informant-rated mentally tough behaviors. When reward sensitivity was low, increases in punishment sensitivity were associated with increased mental toughness. When reward sensitivity was high, increases in punishment sensitivity were associated with decreased mental toughness. These effects, which have also been reported by Beattie, Alqallaf and Hardy (2017), have been explained by the idea that sensitivity to punishment and insensitivity to reward promotes early threat detection. Therefore, individuals who are sensitive to punishment and insensitive to reward are more likely to identify and prepare for stressors well in advance. This increases the likelihood of them displaying mentally tough behaviors (e.g., robust performance) when stressors manifest.

A goal of this thesis was to further investigate the interactive relationship between reward and punishment sensitivities and mentally tough behavior, indexed in this thesis as objective performance during high-stress conditions. Specifically, it set out to test whether the interaction that was reported in professional and competitive athletes by Hardy, Beattie and colleagues (2014, 2017) generalized to also predict mentally tough behaviors in non-trained individuals. Crucially, to build on the theorizing of Hardy et al. (2014), this thesis also examined psychophysiological measures associated with stress reactivity, motor preparation and performance outcomes. These measures allowed further investigation of the proposed mechanisms underpinning why sensitivity to punishment and insensitivity to reward promote mentally tough outcomes. For instance, if early threat detection or better preparation can explain the advantages of this personality profile, one may intuitively expect reduced physiological reactivity and more optimal patterns of preparatory activation in individuals who possess this profile. Accordingly, the psychophysiological insights that this thesis was designed to yield were expected to considerably advance Hardy et al.'s (2014) mental toughness theory. They were also expected to pave the way for biofeedback interventions that encourage the physiological responses that are compatible with MT behaviors. Finally, the thesis also considered the utility of self-report MT measures by assessing their relationships with key personality, psychophysiological, and performance-related measures.

Summary of Findings

Collectively, the two experiments reported in this thesis were designed to provide the most comprehensive and interdisciplinary analysis of mentally tough behavior to date.

Chapter 2. In Chapter 2, novice golfers earned money for each putt they holed during an acquisition phase, before being transferred to a high-stress phase where they had a single-putt whose outcome would determine if they doubled (if final putt was holed) or lost (if final putt was missed) the earnings they had accrued. Their reward and punishment sensitivities and self-reported MT were assessed before they started putting, and a range of cardiac, muscular and movement kinematic measures were assessed during each putt.

Results revealed that sensitivity to reward and punishment interacted to predict the increase in heart rate and muscle activity, and the change in clubhead angle, from the low-stress to the high-stress condition. In brief, the combination of high punishment sensitivity and low reward sensitivity (i.e., the personality profile that yielded mentally tough behaviors in previous research) was associated with reduced heart rate reactivity, perhaps reflecting lower levels of stress, on transitioning from the low-stress to the high-stress condition. It was also associated with less stress-induced changes in technique (i.e., more stable clubhead angle), and increased muscular activity on impact, which may have been functional in maintaining consistent clubhead kinematics under stress.

The heart rate effects were interpreted as supportive of Hardy et al.'s (2014) suggestion that low reward and high punishment sensitivity encourages early threat detection and affords more time to deal with stressors. Specifically, lower heart rate reactivity would be expected in individuals with better alertness to stressors as they should have more chance to employ coping strategies to deal with stressors. The muscle activity and movement kinematic effects were interpreted as supportive of Hardy et al.'s (2014) suggestion that low reward and high punishment sensitivity encourages superior preparation for stressors. Specifically, a bigger increase in forearm muscle activity on impact during the high-stress putt appeared to be functional in encouraging a consistent club-face angle on impact, thereby helping those individuals to maintain consistent technique when pressure intensified.

However, some unexpected findings were also revealed. First, the reward and punishment interactions that emerged were such that the benefits described above for profiles composed of low reward and high punishment sensitivity also emerged for profiles composed of high reward and low punishment sensitivity. It was reasoned that reward sensitivity and punishment insensitivity may be beneficial for non-trained performers as it could promote approach orientation towards high-stress conditions. This effect may have been absent from the previous studies of trained athletes (i.e., Beattie et al., 2017; Hardy et al., 2014) because one would expect all trained athletes to possess some approach motivation in their main sport, but this assumption cannot be taken for granted in non-trained golfers.

Second, personality did not predict changes in heart rate deceleration, proposed to be a key marker of preparation for action (Cooke, 2013; Lacey & Lacey, 1974), from the low-stress to the high-stress condition. This weakens the strength of claims that punishment sensitive and reward insensitive individuals display more mentally tough behaviours because they are better prepared. Finally, in contrast with the findings of Beattie et al. (2017), personality did not predict performance. One note of caution however regarding Beattie et al.'s findings is that performance was assessed in an opening heat of a swimming competition. Therefore, it is not quite clear whether this represented a true stress condition as many swimmers may have been preserving their strength for subsequent heats. What is known however is that swimmers would have had ample time to prepare for their opening heat unlike participants in the present study. Therefore, the extent to which previous findings pertaining to personality and mental toughness in trained athletes generalise to non-trained populations is yet unclear. In any case, the findings in the present Chapter may have been influenced be the late-warning (1 min) provided ahead of the stress condition in this study. This idea is revisited in Chapter 3.

Chapter 3. In Chapter 3, novice golfers participated in pairs, were awarded a £60 prize pot, and then watched each other attempt 30 putts each, with £1 being deduced from the pot every time a putt was missed. They were then transferred to a high-stress condition with one putt each. If both participants missed their putt, all the money remaining in their prize pot was lost, if one participant holed their putt, the contents of the prize pot were retained, if both participants holed their putt, the contents of the prize pot were doubled. Crucially, participants were informed about the high-stress condition at the start of the experiment, thus giving them more time to prepare for their final putt than that one minute of warning that was employed in the previous study. This is important because punishment sensitive individuals may only exhibit mentally tough behavior when they have had enough time to prepare for a stressor (Manley et al., 2017). It was predicted that with early warning for the stressor, the null interactive effects of punishment and reward sensitivities on performance and heart rate deceleration seen in Chapter 2 would be reversed. Once again, reward and punishment sensitivities and self-reported MT were assessed before putting, and a range of cardiac, muscular and movement kinematic measures were assessed during each putt. Cortisol was also assessed as an additional measure of stress reactivity in Chapter 3.

Results revealed that sensitivity to reward and punishment interacted to predict the change in heart rate deceleration and angular error (one index of performance) from the low-stress to the high-stress condition. In brief, the combination of high punishment sensitivity and low reward sensitivity (i.e., the personality profile that yielded mentally tough behaviors in previous research) was associated with a consistent preparatory heart rate deceleration, reflecting a stable preparatory routine across both low-stress and high-stress conditions. It was also associated with more consistent performance across both low-stress and high-stress conditions, with reduced likelihood of stress causing putts to be missed wide of the hole; a common reason for stress-induced impairment of performance in golf novices (Cooke et al., 2010).

The heart rate deceleration effects are interpreted as supportive of Hardy et al.'s (2014) suggestion that low reward and high punishment sensitivity encourages optimal preparation for performing in high-stress conditions. This is because heart rate deceleration during the final moments preceding golf putts characterizes experts compared to novices (e.g., Cooke, 2013; Cooke et al., 2014), while stress typically disrupts heart rate deceleration which may reflect impaired preparation (see Figure 1 in Chapter 2 and Chapter 3). Accordingly, the ability to retain consistent patterns of preparatory heart rate deceleration across both low and high-stress conditions likely indicates the ability to display optimal and consistent preparation even when the stakes are high. Meanwhile, the performance effects are consistent with Beattie et al.'s (2017) finding that high levels of punishment sensitivity and low levels of reward sensitivity are positively associated with performance in competitive swimmers. They are also consistent with Manley et al.'s (2017) finding that punishment sensitivity only benefits performance when sufficient time for preparation is permitted ahead of the high-stress condition. Specifically, reward and punishment sensitivities did not interact to predict performance in Chapter 2, where there was just 1 minute to prepare for the high-stress condition, but they did interact to predict performance in the expected direction with the additional preparation time afforded in Chapter 3.

Interestingly, in accord with Chapter 2, the reward and punishment interactions that emerged were such that the benefits described above for profiles composed of low reward and high punishment sensitivity also emerged for profiles composed of high reward and low punishment sensitivity. This adds further support to the idea that in non-trained performers, relative sensitivity to reward and insensitivity to punishment may be just as beneficial, in terms of encouraging mentally tough behaviours, as high punishment and low reward sensitivity. Further discussion of this observation has already been provided in Chapter 3.

However, there were also some unexpected findings in Chapter 3. Notably, the interactive effects of punishment and reward sensitivities on heart rate reactivity, muscle activity and clubhead kinematics revealed in Chapter 2 were absent in Chapter 3. This was attributed to the change in stress manipulation from Chapter 2 to Chapter 3. While on the one hand, the stress manipulation in Chapter 3 seemed to be more impactful (e.g., higher heart rates than Chapter 2), on the other, the early warning of the stressor in Chapter 3 could have increased excitement and reduced the overall likelihood of stress perturbing technique. In other words, personality is more predictive of our reactivity and technique when we are confronted with a late stressor where trait like behaviors would come to the forefront (Chapter 2) than when we are given early warning of a stressor (Chapter 3) where preparation is key (e.g., Manley et al., 2017). This notion was further supported by the null relations between reward and punishment sensitivities and cortisol, an additional measure of stress reactivity that was obtained in Chapter 3. However, the cortisol protocol may have been confounded by excitement at receiving prize money, limiting its utility as a pure index of stress reactivity. This has already been discussed in Chapter 3.

Finally, it was noted that in both Chapter 2 and Chapter 3, self-reported mental toughness failed to display any consistent correlations with the putative psychophysiological and behavioral measures of mentally tough behavior. This finding provides further ammunition for calls for personality-based or objective physiological or behavioral measures of mental toughness to be used routinely, rather than researchers having reliance on self-reported MT measures. The self-report measures are considered highly susceptible to self-presentation bias (Hardy et al., 2014).

Alternative Interpretations of the Findings

The summaries above provide an overview of the key results and the interpretations of those results in line with the discussions provided in Chapter 2 and Chapter 3. In this final General Discussion Chapter, the findings of both experiments can be integrated, and some alternative interpretations of the data not yet voiced can be considered.

In brief, the three preceding chapters have all focused on the revised reinforcement sensitivity theory (Gray & MacNaughton, 2000) as the theoretical basis for predicting relations between personality and our outcome measures. Moreover, they have argued that reward and punishment sensitivity interact to predict stress reactivity and technique when individuals receive late warning of a stressor, and they interact to predict preparatory activation and performance when individuals receive early warning of a stressor. However, there are other theoretical perspectives could go some way to account for our findings. So far, the different results from Chapter 2 to Chapter 3 have been attributed chiefly to the change from late warning of stressor (Chapter 2) to early warning of stressor (Chapter 3). However, it should be noted that the stress manipulation employed in Chapter 2 and Chapter 3 differed in ways other than just the amount of warning provided. Specifically, the manipulation in Chapter 2, which involved participants accruing money for each successful putt in the acquisition phase, is likely to have primed a promotion focus, as each putt presented an opportunity to gain money. In contrast, the manipulation in Chapter 3, which involved participants losing money for each unsuccessful putt in the acquisition phase, is likely to have primed a prevention focus, as each putt presented an opportunity to lose money.

This change in focus is meaningful in the context of Higgins' theorizing on self-regulation (e.g., Higgins, 1987) and his work on the importance of promotion versus prevention orientations (e.g., Higgins, 1986). Accordingly, this line of research may provide an interesting alternative account of our findings.

Self-regulation, prevention and promotion. The self-regulation theory (Higgins, 1987) provides a subtly different perspective to the revised reinforcement sensitivity theory (rRST; Gray & McNaughton, 2000) on how our motivations influence our way in life. Higgins subscribes to a hedonic principle, the basic tenet of which is that people do things that will bring pleasure and avoid things that will cause pain. He uses this principal to predict how individuals self-regulate, which is the process used to set goals, select ways to reach these goals, and access progress towards goals (e.g. Carver & Scheier, 1990). Higgins argues that the self-regulation system is comprised of two parts, promotion, and prevention. Promotion focus motivates approach and achieve gains, growth, and accomplishment. Prevention focus motivates safety, security, and responsibility to protect the individual from harm.

The promotion system uses approach strategies to regulate behaviours toward desirable ends, and is motivated by the pursuit of ideals, wishes, and aspirations. Higgins uses the example of a tennis player to explain this concept. To be a champion, the tennis player will go to practice even if the practice is very early in the morning. Conversely, the prevention system operates through thoughts of obligation and feeling as if one should or ought to behave in a certain fashion. The prevention system is associated with the regulation of security needs and is shown through the refrainment of actions that would hinder desirable outcomes. For example, this same athlete may avoid late nights and alcohol that would limit the benefit or attending early morning practice. This example illustrates prevention and promotion behaviours and makes a case for individuals having to use both systems and the ability to employ them simultaneously. Higgins (1987) argues that most of the time, one system is momentarily stronger than the other (depending on situational factors, dispositions and motives).

A further related construct relates to loss aversion theory (Tversky & Kahneman, 1992). This theory relates to our stress manipulations of gains vs non-gains and loss vs non-loss (double money, keep money, or lose money). For example, most people would prefer not to lose £5 than to find £5 and losses have been reported twice as powerful, psychologically, as gains (Tversky & Kahneman, 1992). Research has also found that it is believed that most people have a stronger aversion to losing than to not winning (Kahneman, Knetsch & Thaler, 1986; Tversky, 1994; Liberman, Idson, & Higgins, 2005). Further, Liberman et al. (2005) reported that for most people, not losing is not as positive or pleasurable as winning or gaining is. For example, the behaviours of sport performers after losing points tend to show stronger negative feelings than after failing to acquire points. Conversely, athletes tend to display stronger positive behaviours after winning points than avoiding losing points.

The pay-off matrix of any given situation can also prime a promotion or prevention focus. For example, in Chapter 2, the manipulation in the acquisition phase is likely to have primed a promotion focus as the emphasis was on gain vs non-gain. Then, in the high-stress condition, there was the opportunity to double money, or lose everything, which could have elicited a promotion (focus on double money) or prevention (focus on not losing) orientation.

It is possible that participants who were sensitive to punishment and insensitive to reward were able to adopt a clear prevention focus in the high-stress condition, which is compatible with their personality, and likely not as stressful as being encouraged to adopt a promotion focus as was the case during acquisition. This could explain their blunted heart rate reactivity from low-stress to high-stress in Chapter 2. Relatedly, participants who were sensitive to reward and insensitive to punishment may have been able to adopt a clear promotion focus in the high-stress condition, compatible with their personality and the focus that was primed during the acquisition phase. Hence, these participants also demonstrated blunted reduced heart rate reactivity in the high-stress condition. Conversely, participants with similar levels of reward and punishment sensitivity may have been more conflicted in whether to adopt a promotion or prevention focus in the high-stress condition since there is a less obvious personality bias to one orientation over the other. Internal conflict is often stressful could explain the elevated heart rate reactivity in such participants.

In contrast, the pay-off matrix in Chapter 3 is likely to have primed a prevention focus in the acquisition phase, as the emphasis was on not losing money, without any opportunity for gains (i.e., loss vs non-loss). Then, in the high-stress condition, there was the opportunity to double money, keep money, or lose everything, which could have elicited a promotion (focus on double money) or prevention (focus on not losing) orientations. However, there was an additional level of complexity in Chapter 3. Specifically, as participants completed the study in pairs, the order in which they attempted the final putt would influence the situation. For example, participants who attempted the final putt first may have adopted the promotion or prevention orientation most compatible with their personality (e.g., more punishment sensitive individuals focus on prevention while more reward sensitive individuals focus on promotion). However, those who attempted the final putt second may have been influenced by the outcome of their partner's putt. For example, if the first putt was holed, the money had already been secured and the payoff matrix for the second participant was now promotion only (i.e., opportunity to double money, with no opportunity for loss). In contrast, if the first putt was missed, the payoff matrix for the second participant was now prevention only (i.e., chance of losing the money, no opportunity for further gains). Thus, some participants who went second in the high-stress condition may have been primed by the situation to adopt a self-regulatory orientation incompatible with their default, while others would have been primed with a compatible orientation. The sum of all these permutations is likely to have elicited considerable variability in stress-reactivity and clouded the ability of reward and punishment tendencies to predict heart rate change from low-stress to high-stress condition. This could account for why reward and punishment sensitivities interacted to predict heart rate change in Chapter 2, but not Chapter 3. Instead, they interacted to predict the change in heart rate deceleration, an index of preparation consistency, in Chapter 3. It is possible that this index is less influenced by prevention and promotion focus, and more influenced the extent to which an individual is prepared for performing under stress. In Chapter 3, it is argued that the early warning about the stressor primed participants who were relatively high in one of punishment or reward, and low in the other, to use this warning to better effect and prepare better than individuals with conflicted personality profiles.

This alternative interpretation of the data is admittedly speculative, especially since promotion versus prevention orientations were not assessed. However, it is worthy of consideration in future studies investigating the relationship between personality and mentally tough behaviours. It offers the enticing possibility of identifying individuals who may be particularly likely to demonstrate mentally tough behaviours under promotion-laden versus prevention-laden condition. This information could be incredibly valuable in selecting individuals for certain key roles in a plethora of pressured domains including business and sport (e.g., identifying a player to bat through the innings to draw a high-stress game of cricket; versus identifying a play to score runs quickly and win).

Thesis Limitations

While the findings in this thesis shed some new light on the relations between personality, mental toughness and performance, they should be interpreted by considering a few limitations. Principally, changing multiple aspects of the stress manipulation from Chapter 2 to Chapter 3 make the different results across the two experiments more difficult to interpret. For instance, the change from late warning (Chapter 2) to early warning of the stressor (Chapter 3), is considered the most likely candidate to explain the different findings. However, as discussed above, changes in the payoff matrix, and even changes in the social environment (i.e., additional peer pressure in Chapter 3) could also have played a role. Future research can more tightly control each of these aspects of the stress manipulation to shed even more light on our findings and the candidate interpretations. For example, social pressure was much higher in Chapter 3 (playing for a combined pot of money) than it was in Chapter 2 (playing for your own money).

Second, the use of non-trained participants resulted in considerable within- and between-person variability in performance. While using non-trained participant is a strength in terms of testing the generalisability of previous findings in trained populations (e.g., Beattie et al., 2017; Hardy et al., 2014), the additional noise created by highly variable data may limit the ability to detect statistically meaningful effects. Large sample sizes were adopted in both experiments here to attempt to mitigate these effects, and power calculations indicated that adequate statistical power should have been achieved. However, increasing the sample size to boost statistical power, or replicating the current sample with a more homogenous population (e.g., golf experts) would allow for more rigorous tests of the replicability of the current findings.

Third, adopting stress conditions that were more distinct and thereby created more extreme levels of low- versus high-stress may allow stronger effects to emerge. Manipulation checks satisfied the requirement for distinct low and high-stress conditions in this thesis. However, it should be conceded that even in the so-called low-stress condition, participants had recently completed putts during the acquisition phase that had financial consequences. Accordingly, they were likely under some pressure in the low-stress condition. Pressure in the low-stress condition may have been amplified further in Chapter 3 by the presence of a peer, and the associated elevations in social evaluation and opportunity for social comparison. In support of this suggestion, average heart rates of 85 and 88 beats per minute, respectively, were recorded in the low-stress condition in Chapter 2 and Chapter 3. These low-stress heart rates are higher than the 79 beat per minute low-stress heart rate reported by Cooke et al. (2010) in a study with a similar population of novice golfers. That study used a manipulation that explicitly attempted to disguise the low-stress condition by informing participants that their performance was not being evaluated, rather, the researchers were interested in the accuracy of different types of golf balls (golf balls with different markings were used to bolster the disguise). Future studies could use similar guises to minimise evaluation apprehension in low-stress conditions and create more distinct stress groups. At the other end of the spectrum, greater rewards or consequences could be attached to performance to amplify the effectiveness of the high-stress condition.

Finally, the cortisol measure employed in Chapter 3 was not effective at distinguishing low-stress from high-stress conditions. This can be attributed to the low-stress cortisol sample being obtained at a time when most participants were anticipating the payment of prize money. Since cortisol may be influenced by excitement and reward in addition to stress (e.g., Ott et al., 2011), future studies going to the trouble of assessing cortisol as an index of stress should ensure that their low-stress sample is obtained in a both a low-stress and a low-arousal situation. Cortisol was of limited utility in advancing the theoretical aims of this thesis, but it may still prove a fruitful measure for future research if it is obtained in suitably distinct and pure low- and high-stress conditions.

Thesis Strengths

The main strength of the experiments reported in this thesis are their rigorous multi-measure and interdisciplinary approach to mental toughness assessment. These are the first experiments to combine personality, psychophysiological, kinematic and performance outcome measures and examine multi-level regression-based hypotheses in the mental toughness literature. Moreover, they are among the largest psychophysiological studies of this type, with previous studies examining psychophysiological and kinematic variables during motor performance typically containing samples of 30-50 participants (e.g., Boucher & Zinsser, 1990; Neuman & Thomas, 2009), and even the biggest studies (e.g., Cooke, Kavussanu, McIntyre & Ring, 2011) not exceeding 100 participants, which was exceeded in Chapter 3 of this thesis. Large interdisciplinary studies of this nature have the advantage of being able to examine mechanistic questions to understand the complex inter-relations among variables. For example, this thesis sheds light on how the previously reported relations between personality and performance manifest via the interactive effects of personality on key factors that influence performance such as kinematic technique and stress reactivity. In doing so, this thesis provides the first steps towards an interdisciplinary psychophysiological model of mentally tough behaviour. It is hoped that future research builds from the groundwork that has been conducted here, and further develops this multifaceted conceptualisation of mental toughness.

Enticingly, this thesis also sheds some light on the most important physiological parameters to encourage optimal technique and or performance. Specifically, based on the findings of Chapter 2, one can speculate that to optimally prepare individuals for dealing with late stressors, they should be furnished with coping skills to help them keep their stress reactivity under control, and maintain good technique. If participants were skilled in practicing strategies such as relaxation or paced breathing, the elevated stress reactivity that occurred for some participants when they encountered the late stressor may not have been as prominent. Similarly, based on the findings of Chapter 3, one can speculate that to optimally prepare individuals for dealing with any kind of stressor (especially early stressors), they should be equipped with consistent pre-performance routines (e.g., Cotterill, 2010). This could minimise the chances of stress disrupting preparatory / readiness patterns, and, in turn, reduce the likelihood of stress having an adverse effect on behaviour. Future studies could test these predictions directly via applied interventions with skilled performers, or experimental studies manipulating which group of participants receive the intervention, and which group do not.

Conclusion

In conclusion, this body of work provides further evidence to endorse reward and punishment sensitivities as important personality traits that can interact to predict mentally tough behaviour. Specifically, it indicates that individuals who are relatively sensitive to punishment and insensitive to reward, or sensitive to reward and insensitive to punishment, are more likely to display mentally tough behaviours on novel motor tasks then individuals with more balanced personality profiles. Moreover, it provides evidence that these effects are explained by such individuals being less perturbed by stressors on a range of physiological and kinematic measures that are important for regulating performance. The findings can have important implications for personality screening and person selection to high-stakes roles where mentally tough behaviours are key. They can also provide the foundations for interventions to build mentally tough outcomes, even in participants who do not have the personality profiles typically linked to mental toughness behaviours. These enticing applied implications should be pursued by future research.

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Appendices

Supplementary analyses

The Main and Interactive Effects of Punishment and Reward Sensitivities on Heart Rate

Point time	Constant	B	Std. Error	Compared R^2 change	Sig.
		5.81	1.68		.001
HR 6 Secs. diff	R	1.29	1.71	.020	.451
	P	.60	1.72	.000	.727
	P x R	3.57	2.03	.045	.083
HR 5.5 Secs. diff	Constant	6.01	1.61		.000
	R	.79	1.63	.013	.629
	P	.66	1.64	.000	.688
	P x R	3.90	1.94	.059	.048
HR 5 Secs. diff	Constant	6.21	1.57		.000
	R	-.03	1.59	.004	.985
	P	.023	1.60	.003	.989
	P x R	3.81	1.88	.060	.047
HR 4.5 Secs. diff	Constant	6.25	1.58		.000
	R	-.85	1.60	.000	.596
	P	-.38	1.61	.008	.814
	P x R	4.28	1.90	.073	.028
HR 4 Secs. diff	Constant	6.23	1.61		.000
	R	-1.03	1.63	.000	.531
	P	-.97	1.64	.016	.557
	P x R	3.99	1.94	.061	.043
HR 3.5 Secs. diff	Constant	6.77	1.65		.000
	R	-1.27	1.67	.000	.450
	P	-1.13	1.68	.018	.503
	P x R	3.96	1.98	.058	.050
HR 3 Secs. diff	Constant	7.04	1.63		.000
	R	-.98	1.65	.000	.553
	P	-.70	1.66	.010	.675
	P x R	3.71	1.96	.053	.063
HR 2.5 Secs. diff	Constant	7.33	1.61		.000
	R	-.51	1.63	.001	.753
	P	-.35	1.64	.006	.830
	P x R	3.48	1.94	.048	.078
HR 2 Secs. diff	Constant	7.38	1.61		.000
	R	-.20	1.63	.002	.900
	P	.21	1.64	.001	.896
	P x R	3.65	1.93	.052	.064
HR 1.5 Secs. diff	Constant	8.10	1.52		.000
	R	.11	1.54	.005	.940
	P	.14	1.55	.002	.926
	P x R	3.72	1.83	.060	.047
HR 1 Secs. diff	Constant	8.70	1.40		.000
	R	.53	1.42	.011	.711
	P	.21	1.43	.001	.882
	P x R	3.20	1.69	.052	.063
HR .05 Secs. diff	Constant	9.01	1.34		.000
	R	.78	1.36	.014	.567

	P	.42	1.37	.000	.756
	P x R	2.71	1.62	.041	.099
HR .00 Secs. diff	Constant	10.06	1.31		.000
	R	.65	1.33	.010	.627
	P	.58	1.34	.000	.662
	P x R	2.51	1.58	.037	.118

The Main and Interactive Effects of Punishment and Reward Sensitivities on Muscle Activity (flexor)

Point time	**Constant**	**B**	**Std. Error**	**Compared R^2 change**	**Sig.**
		3.16	1.56		.047
EMG 6 Secs. diff	R	3.02	1.57	.033	.059
	P	2.81	1.59	.049	.082
	P x R	-.49	1.87	.001	.792
EMG 5.5 Secs. diff	Constant	5.45	2.52		.035
	R	3.06	2.55	.001	.234
	P	5.05	2.58	.054	.054
	P x R	.95	3.03	.001	.755
EMG 5 Secs. diff	Constant	3.55	2.05		.088
	R	3.33	2.06	.016	.112
	P	3.75	2.09	.057	.077
	P x R	-1.95	2.46	.009	.430
EMG 4.5 Secs. diff	Constant	1.80	1.84		.332
	R	3.29	1.86	.015	.082
	P	5.10	1.88	.111	.009
	P x R	-1.32	2.22	.005	.553
EMG 4 Secs. diff	Constant	-1.42	1.73		.414
	R	1.93	1.75	.008	.273
	P	.815	1.77	.008	.647
	P x R	-2.73	2.08	.025	.194
EMG 3.5 Secs. diff	Constant	1.12	2.04		.585
	R	-.26	2.06	.009	.897
	P	3.69	2.08	.057	.081
	P x R	-2.25	2.45	.012	.360
EMG 3 Secs. diff	Constant	-1.64	1.60		.310
	R	.76	1.62	.002	.640
	P	1.80	1.64	.037	.277
	P x R	-4.90	1.93	.087	.013
EMG 2.5 Secs. diff	Constant	.42	1.71		.804
	R	.49	1.73	.001	.776
	P	2.92	1.75	.052	.100
	P x R	-1.84	2.05	.011	.375
EMG 2 Secs. diff	Constant	.800	1.59		.618
	R	-1.19	1.61	.021	.461
	P	2.46	1.63	.038	.136
	P x R	-.64	1.91	.002	.737
EMG 1.5 Secs. diff	Constant	1.84	1.56		.241
	R	-.47	1.57	.016	.765
	P	3.63	1.59	.086	.026
	P x R	-1.59	1.87	.010	.397
EMG 1 Secs. diff	Constant	3.35	1.69		.052
	R	.75	1.70	.001	.661
	P	3.99	1.72	.085	.024
	P x R	-1.00	2.03	.003	.624
EMG .05 Secs. diff	Constant	3.08	1.82		.095
	R	1.06	1.83	.002	.563
	P	1.50	1.85	.013	.420

	P x R	-.87	2.18	.002	.690
EMG .00 Secs. diff	Constant	5.62	2.33		.01
	R	.91	2.35	.003	.70
	P	2.36	2.38	.032	.32
	P x R	-6.88	2.80	.082	.017

The Main and Interactive Effects of Punishment and Reward Sensitivities on Extensor Muscle Activity

Point time	**Constant**	**B**	**Std. Error**	**Compared R^2 change**	**Sig.**
		1.00	1.12		.37
EMG 6 Secs. diff	R	2.00	1.13	.029	.08
	P	.18	1.14	.003	.87
	P x R	-2.09	1.34	.035	.12
EMG 5.5 Secs. diff	Constant	1.59	1.50		.29
	R	1.74	1.52	.013	.25
	P	.36	1.53	.002	.81
	P x R	-1.40	1.81	.009	.44
EMG 5 Secs. diff	Constant	1.09	1.15		.34
	R	1.92	1.16	.029	.10
	P	.37	1.17	.004	.74
	P x R	-1.38	1.38	.015	.32
EMG 4.5 Secs. diff	Constant	-.24	1.25		.84
	R	1.62	1.26	.014	.20
	P	1.06	1.27	.015	.40
	P x R	-1.12	1.50	.008	.45
EMG 4 Secs. diff	Constant	-.22	1.10		.84
	R	.97	1.11	.008	.38
	P	-.18	1.12	.000	.87
	P x R	-1.28	1.32	.014	.33
EMG 3.5 Secs. diff	Constant	.91	1.36		.50
	R	.74	1.37	.001	.59
	P	.60	1.39	.006	.66
	P x R	-1.41	1.63	.74	.39
EMG 3 Secs. diff	Constant	.29	1.24		.81
	R	.66	1.25	.003	.59
	P	-.80	1.26	.003	.53
	P x R	-1.34	1.49	.012	.37
EMG 2.5 Secs. diff	Constant	-.01	1.11		.98
	R	.39	1.12	.002	.72
	P	-1.42	1.13	.017	.21
	P x R	-1.41	1.33	.017	.29
EMG 2 Secs. diff	Constant	-.15	.89		.86
	R	-.50	.90	.002	.57
	P	-1.45	.91	.034	.11
	P x R	-.52	1.07	.004	.62
EMG 1.5 Secs. diff	Constant	1.16	.69		.09
	R	-.39	.69	.008	.57
	P	-.33	.70	.001	.63
	P x R	-.75	.83	.013	.36
EMG 1 Secs. diff	Constant	2.40	.78		.003
	R	-.66	.79	.013	.40
	P	-.09	.79	.000	.91
	P x R	-.19	.94	.001	.83
EMG .05 Secs. diff	Constant	1.11	.73		.13
	R	-.25	.74	.000	.72
	P	-1.07	.74	.028	.15

	P x R	-.34	.88	.002	.69
EMG .00 Secs. diff	Constant	2.96	1.13		.01
	R	-.12	1.14	.006	.97
	P	-.28	1.16	.001	.81
	P x R	-3.20	1.36	.078	.02

The Main and Interactive Effects of Punishment and Reward Sensitivities on Kinematic Movement

Point time	**Constant**	**B**	**Std. Error**	**Compared R^2 change**	**Sig.**
		18.99	13.15		.154
Back Swing Time. diff	R	-32.90	12.75	.113	.012
	P	5.71	13.74	.002	.679
	P x R	2.32	15.86	.000	.884
Foreword Swing Time. diff	Constant	-.198	4.89		.602
	R	-5.95	4.78	.020	.179
	P	-6.61	5.10	.026	.826
	P x R	-1.99	5.94	.002	.793
Putt of performance	Constant	-.228	5.949		.970
	R	-3.045	6.044	.004	.616
	P	-.694	6.060	.000	.909
	P x R	-1.042	7.191	.000	.885
Mean Radial Error. diff	Constant	56.253	49.007		.256
	R	12.635	47.862	.000	.793
	P	44.449	51.061	.013	.388
	P x R	-6.097	59.547	.000	.919
Max_Ball Velocity. diff	Constant	71.335	34.645		.044
	R	-8.031	33.836	.008	.813
	P	51.406	36.098	.038	.160
	P x R	-33.678	42.097	.010	.427
Distance long versus short	Constant	82.187	51.597		.117
	R	-16.898	50.392	.006	.739
	P	104.458	53.760	.058	.057
	P x R	21.506	62.694	.002	.733
Left_Right_Distance	Constant	25.858	16.629		.125
	R	-10.301	16.241	.014	.528
	P	10.734	17.327	.008	.538
	P x R	-12.910	20.206	.007	.525
Angle of error	Constant	-.667	.318		.040
	R	.094	.310	.000	.764
	P	-.052	.331	.000	.875
	P x R	-.671	.386	.049	.087
Angle of error_dev	Constant	.516	.241		.036
	R	.104	.235	.001	.660

	P	.114	.251	.005	.651
	P x R	-.252	.293	.012	.392
X-axis Velocity. diff	Constant	38.677	16.704		.024
	R	-14.566	16.314	.023	.376
	P	21.403	17.405	.026	.224
	P x R	-4.562	20.297	.001	.823
Y_ axis Velocity. diff	Constant	11.911	9.614		.220
	R	1.462	9.389	.000	.877
	P	27.796	10.017	.107	.007
	P x R	11.102	11.681	.013	.346
Z_ axis Velocity. diff	Constant	1.050	3.570		.770
	R	5.154	3.487	.039	.145
	P	-4.303	3.720	.018	.252
	P x R	-3.335	4.338	.009	.445
Over_shoot.dev.Diff	Constant	123.130	47.379		.012
	R	18.766	46.273	.000	.687
	P	77.656	49.366	.042	.121
	P x R	-7.342	57.570	.000	.899
LR.dev.Diff	Constant	29.829	12.482		.020
	R	2.767	12.191	.000	.821
	P	12.218	13.005	.018	.351
	P x R	-10.878	15.167	.008	.476
Clubhead angle_100fs. diff	Constant	.078	.277		.779
	R	-.304	.271	.019	.266
	P	-.427	.289	.029	.145
	P x R	-.335	.337	.016	.323
Clubhead angle_100fs_ dev. diff	Constant	.715	.173		.000
	R	-.050	.169	.000	.770
	P	.217	.180	.012	.233
	P x R	.495	.210	.085	.022

Supplementary Analyses – Cortisol – Chapter 3

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Cotisol.S
2	Cotisol.C

Between-Subjects Factors

		Value Label	N
1 = keep	.00	lose	35
	1.00	keep	46
	2.00	double	22

Descriptive Statistics

	1 = keep	Mean	Std. Deviation	N
Cotisol.S	lose	5.3554	2.22710	35
	keep	5.6547	3.05288	46
	double	5.5575	3.12404	22
	Total	5.5323	2.79143	103
Cotisol.C	lose	5.7111	2.77195	35
	keep	8.0445	5.00216	46
	double	7.3966	4.72753	22
	Total	7.1132	4.39142	103

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
factor1	Pillai's Trace	.105	11.685[b]	1.000	100.000	.001	.105
	Wilks' Lambda	.895	11.685[b]	1.000	100.000	.001	.105
	Hotelling's Trace	.117	11.685[b]	1.000	100.000	.001	.105
	Roy's Largest Root	.117	11.685[b]	1.000	100.000	.001	.105
factor1 * Doub_Lose_Keep	Pillai's Trace	.043	2.239[b]	2.000	100.000	.112	.043
	Wilks' Lambda	.957	2.239[b]	2.000	100.000	.112	.043
	Hotelling's Trace	.045	2.239[b]	2.000	100.000	.112	.043
	Roy's Largest Root	.045	2.239[b]	2.000	100.000	.112	.043

a. Design: Intercept + Doub_Lose_Keep
Within Subjects Design: factor1

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
factor1	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Doub_Lose_Keep
Within Subjects Design: factor1

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
factor1	Sphericity Assumed	109.740	1	109.740	11.685	.001	.105
	Greenhouse-Geisser	109.740	1.000	109.740	11.685	.001	.105
	Huynh-Feldt	109.740	1.000	109.740	11.685	.001	.105
	Lower-bound	109.740	1.000	109.740	11.685	.001	.105
factor1 * Doub_Lose_Keep	Sphericity Assumed	42.050	2	21.025	2.239	.112	.043
	Greenhouse-Geisser	42.050	2.000	21.025	2.239	.112	.043
	Huynh-Feldt	42.050	2.000	21.025	2.239	.112	.043
	Lower-bound	42.050	2.000	21.025	2.239	.112	.043
Error(factor1)	Sphericity Assumed	939.143	100	9.391			
	Greenhouse-Geisser	939.143	100.000	9.391			
	Huynh-Feldt	939.143	100.000	9.391			
	Lower-bound	939.143	100.000	9.391			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	factor1	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
factor1	Linear	109.740	1	109.740	11.685	.001	.105
factor1 * Doub_Lose_Keep	Linear	42.050	2	21.025	2.239	.112	.043
Error(factor1)	Linear	939.143	100	9.391			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	7428.557	1	7428.557	434.315	.000	.813
Doub_Lose_Keep	70.216	2	35.108	2.053	.134	.039
Error	1710.407	100	17.104			

Custom Hypothesis Tests

Contrast Results (K Matrix)

Helmert Contrast			Averaged Variable MEASURE_1
Level 1 vs. Later	Contrast Estimate		-1.130
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		-1.130
	Std. Error		.623
	Sig.		**.073**
	95% Confidence Interval for Difference	Lower Bound	-2.366
		Upper Bound	.106
Level 2 vs. Level 3	Contrast Estimate		.373
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		.373
	Std. Error		.758
	Sig.		.624
	95% Confidence Interval for Difference	Lower Bound	-1.131
		Upper Bound	1.877

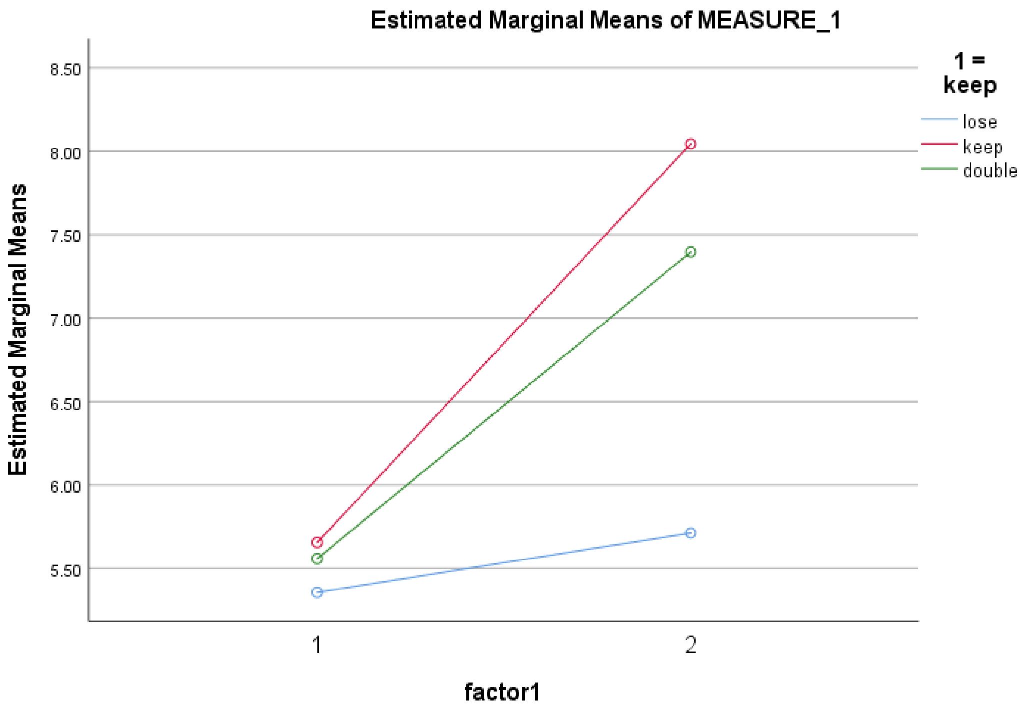
Test Results

Measure: MEASURE_1

Transformed Variable: AVERAGE

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	35.108	2	17.554	2.053	.134	.039
Error	855.204	100	8.552			

Profile Plots



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Questionnaires

Investigation: A multidisciplinary approach to examine Mental Toughness

- **Reward and Punishment Sensitivity. The EPQR-S (Eysenck, Eysenck, & Barrett, 1985)**
- **The Mental Toughness Questionnaire-48 (MTQ48; Clough et al., 2002)**
- **The Mental Toughness Index (MTI; Gucciardi et al., 2014)**
- **Sport Mental Toughness Questionnaire (SMTQ; Sheard et al., 2008)**
- **Mental Readiness Form-3 (MRF-3, Krane, 1994)**

Name

Age

Gender

Email address

Date

Experience

Any health problems?

(Personality Measures)

Turki Alzahrani
Dr. Beattie, Dr. Hardy and Dr. Cooke

2017

Reward and Punishment Sensitivity:
Instructions: Please answer each question by putting a circle around the ‘YES or the ‘NO’ following the question. There are no right or wrong answers, and no trick questions. Work quickly and do not think too long about the exact meaning of the questions.

PLEASE REMEMBER TO ANSWER EACH QUESTION

1. Does your mood often go up and down?	YES	NO
2. Do you take much notice of what other people think?	YES	NO
3. Are you a talkative person?	YES	NO
4. Do you ever feel 'just miserable' for no reason?	YES	NO
5. Would being in debt worry you?	YES	NO
6. Are you rather lively?	YES	NO
7. Are you an irritable person?	YES	NO
8. Would you take drugs which may have strange or dangerous effect?	YES	NO
9. Do you enjoy meeting new people?	YES	NO
10. Are your feeling easily hurt?	YES	NO
11. Do you prefer to go your own way rather than act by the rules?	YES	NO
12. Can you usually let yourself go and enjoy yourself at a lively party?	YES	NO
13. Do you often feel fed-up?	YES	NO
14. Do good manners and cleanliness matter much to you?	YES	NO
15. Do you usually take the initiative in making new friends?	YES	NO
16. Would you call yourself a nervous person	YES	NO
17. Do you think marriage is old-fashioned and should be done away with?	YES	NO
18. Can you easily get some life into a rather dull party?	YES	NO
19. Are you a worrier?	YES	NO
20. Do you enjoy co-operating with others?	YES	NO
21. Do you tend to keep in the background in social occasions?	YES	NO
22. Does it worry you if you know there are mistakes in your work?	YES	NO
23. Would you call yourself tense or 'highly-strung'?	YES	NO
24. Do you think people spend too much time safeguarding their future with savings and insurances?	YES	NO
25. Do you like mixing with people?	YES	NO
26. Do you worry too long after an embarrassing experience?	YES	NO
27. Do you try not to be rude to people?	YES	NO
28. Do you like plenty of bustle and excitement around you?	YES	NO
29. Do you suffer from 'nerves'?	YES	NO
30. Would you like other people to be afraid of you?	YES	NO
31. Are you mostly quiet when you are with other people?	YES	NO
32. Do you often feel lonely?	YES	NO
33. Is it better to follow society's rules than go your own way?	YES	NO
34. Do other people think of you as being very lively?	YES	NO
35. Are you often troubled about feelings of guilt?	YES	NO
36. Can you get a party going?	YES	NO

The Mental Toughness Questionnaire-48:

Please answer these items carefully, thinking about how you are generally. Do not spend too much time on any one item.

	◂◂Disagree				Agree▸▸
1) I usually find something to motivate me	1	2	3	4	5
2) I generally feel in control	1	2	3	4	5
3) I generally feel that I am a worthwhile person	1	2	3	4	5
4) Challenges usually bring out the best in me	1	2	3	4	5
5) When working with other people I am usually quite influential	1	2	3	4	5
6) Unexpected changes to my schedule generally throw me	1	2	3	4	5
7) I don't usually give up under pressure	1	2	3	4	5
8) I am generally confident in my own abilities	1	2	3	4	5
9) I usually find myself just going through the motions	1	2	3	4	5
10) At times I expect things to go wrong	1	2	3	4	5
11) "I just don't know where to begin" is a feeling I usually have when presented with several things to do at once	1	2	3	4	5
12) I generally feel that I am in control of what happens in my life	1	2	3	4	5
13) However bad things are, I usually feel they will work out positively in the end	1	2	3	4	5
14) I often wish my life was more predictable	1	2	3	4	5
15) Whenever I try to plan something, unforeseen factors usually seem to wreck it	1	2	3	4	5
16) I generally look on the bright side of life	1	2	3	4	5
17) I usually speak my mind when I have something to say	1	2	3	4	5
18) At times I feel completely useless	1	2	3	4	5
19) I can generally be relied upon to complete the tasks I am given	1	2	3	4	5
20) I usually take charge of a situation when I feel it is appropriate	1	2	3	4	5
21) I generally find it hard to relax	1	2	3	4	5
22) I am easily distracted from tasks that I am involved with	1	2	3	4	5
23) I generally cope well with any problems that occur	1	2	3	4	5
24) I do not usually criticise myself even when things go wrong	1	2	3	4	5
25) I generally try to give 100%	1	2	3	4	5
26) When I am upset or annoyed I usually let others know	1	2	3	4	5
27) I tend to worry about things well before they actually happen	1	2	3	4	5
28) I often feel intimidated in social gatherings	1	2	3	4	5
29) When faced with difficulties I usually give up	1	2	3	4	5
	◂◂Disagree				Agree▸▸
30) I am generally able to react quickly when something unexpected happens	1	2	3	4	5
31) Even when under considerable pressure I usually remain calm	1	2	3	4	5
32) If something can go wrong, it usually will	1	2	3	4	5

33) Things just usually happen to me	1	2	3	4	5
34) I generally hide my emotion from others	1	2	3	4	5
35) I usually find it difficult to make a mental effort when I am tired	1	2	3	4	5
36) When I make mistakes I usually let it worry me for days after	1	2	3	4	5
37) When I am feeling tired I find it difficult to get going	1	2	3	4	5
38) I am comfortable telling people what to do	1	2	3	4	5
39) I can normally sustain high levels of mental effort for long periods	1	2	3	4	5
40) I usually look forward to changes in my routine	1	2	3	4	5
41) I feel that what I do tends to make no difference	1	2	3	4	5
42) I usually find it hard to summon enthusiasm for the tasks I have to do	1	2	3	4	5
43) If I feel somebody is wrong, I am not afraid to argue with them	1	2	3	4	5
44) I usually enjoy a challenge	1	2	3	4	5
45) I can usually control my nervousness	1	2	3	4	5
46) In discussions, I tend to back-down even when I feel strongly about something	1	2	3	4	5
47) When I face setbacks I am often unable to persist with my goal	1	2	3	4	5
48) I can usually adapt myself to challenges that come my way	1	2	3	4	5

The Mental Toughness Index:

INSTRUCTIONS: Using the scale below, please indicate how true each of the following statements is an indication of how you typically think, feel, and behave as an athlete – *remember there are no right or wrong answers so be as honest as possible*.

1	2	3	4	5	6	7
False, 100% of the time						*True, 100% of the time*

1	I believe in my ability to achieve my goals	1	2	3	4	5	6	7
2	I am able to regulate my focus when performing tasks	1	2	3	4	5	6	7
3	I am able to use my emotions to perform the way I want to	1	2	3	4	5	6	7
4	I strive for continued success	1	2	3	4	5	6	7
5	I execute my knowledge of what is required to achieve my goals	1	2	3	4	5	6	7
6	I consistently overcome adversity	1	2	3	4	5	6	7
7	I am able execute appropriate skills or knowledge when challenged	1	2	3	4	5	6	7
8	I can find a positive in most situations	1	2	3	4	5	6	7

Sport Mental Toughness Questionnaire:

INSTRUCTIONS: Using the scale below, please indicate how true each of the following statements is an indication of how you typically think, feel, and behave as an athlete – *remember there are no right or wrong answers so be as honest as possible*.

1	2	3	4
Not all True			*Very True*

1	I can regain my composure if I have momentarily lost it	1	2	3	4
2	I worry about performing poorly	1	2	3	4
3	I am committed to completing the tasks I have to do	1	2	3	4
4	I am overcome by self-doubt	1	2	3	4
5	I have an unshakeable confidence in my ability	1	2	3	4
6	I have what it takes to perform well while under pressure	1	2	3	4
7	I get angry and frustrated when things do not go my way	1	2	3	4
8	I give up in difficult situations	1	2	3	4
9	I get anxious by events I did not expect or cannot control	1	2	3	4
10	I get distracted easily and lose my concentration	1	2	3	4
11	I have qualities that set me apart from other competitors	1	2	3	4
12	I take responsibility for setting myself challenging targets	1	2	3	4
13	I interpret potential threats as positive opportunities	1	2	3	4
14	Under pressure, I am able to make decisions with confidence and commitment	1	2	3	4

Mental Readiness Form-3:

<u>Before you putt on this trial please tell us how you feel right now</u>

My thoughts are:

1 / 2 / 3 / 4 /5 /6 / 7 / 8 / 9 / 10 / 11

CALM WORRIED

My body feels:

1 / 2 / 3 / 4 /5 /6 / 7 / 8 / 9 / 10 / 11

RELAXED TENSE

I am feeling:

1 / 2 / 3 / 4 /5 /6 / 7 / 8 / 9 / 10 / 11

CONFIDENT SCARED

Saliva labelling, collection and handling SOP

- Collect saliva at approximately the same time of day (± 1 hour) each time.

Equipment:

- Centrifuge
- Weighing scale accurate to 3 decimal places.
- Portable fridge (4°C)
- -80°C freezer
- Chair
- Stopwatch

Consumables:

- Universal container
- Blue eppendorfs
- Pastettes (or 10-100 µL pipette and pipette tips)
- Gloves
- Tissue

Labelling (wear gloves):

For each participant:

- Weigh 1x universal container to 3 decimal places. Label the universal container with the participant’s UIN (e.g. 001-W13), surname and eppendorf mass.
- Label (side and lid) 4x blue eppendorfs with the participant’s UIN (e.g. 001-W13).

Saliva collection:

- Ensure participants have **avoided consuming food and fluid for 15 minutes** prior to saliva collection.
- Collect saliva from participants simultaneously following 5 minutes seated rest. Distribute to participants their pre-weighed and labelled universal container.
- Ask participants to remove the lid and then swallow any saliva in their mouth.
- Ask participants to drool into the universal container for **5 minutes** with minimal orofacial movement. Ask participants to avoid talking.
- Participants should lean forward and place the container to their mouth, allowing saliva to collect in the front of their mouth and drool into the container (Figure 1).
- Ask participants to avoid spitting into the universal container.
- After 5 minutes, ask the participants to stop the collection and close the lid.
- Aim to collect saliva to the top of the cone shape of the universal container (Figure 2).
- If this mark has not been reached, continue the collection for a further 2 minutes. Record the total collection time for each participant (5 or 7 minutes).
- Immediately following collection, store the universal container in the portable fridge (4°C). Record the collection time of day.

Figure 1

Figure 2

Saliva Handling:

- Within 3 hours of collection, measure the mass of the universal container, lid and collected saliva (to 3 decimal places). Record the volume of saliva collected (assuming a density of 1.0 g/mL).
- Using a pastette or pipette, aliquot an equal volume of saliva into 4 blue eppendorfs (match universal tube UIN to eppendorf UIN) (Figure 3).
- Freeze the 4 blue eppendorfs immediately at -80°C.

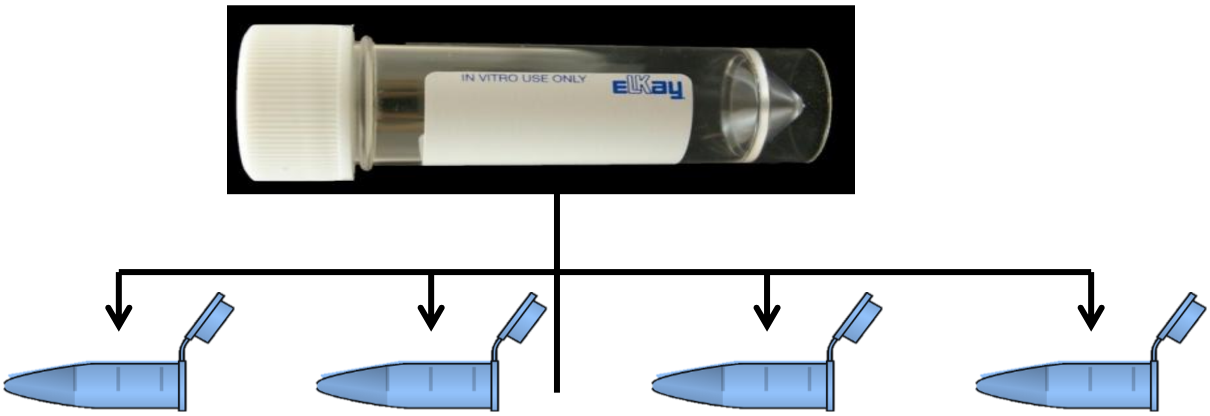

Figure 3

Participant Information Sheet

PRIFYSGOL BANGOR UNIVERSITY

Title: Examining the effects of personality and learning in golf putting

Dear Participant,

Before you decide to take part in this research study, it is important for you to understand what it will involve. Please take time to read the following information carefully and discuss it with the investigator if you wish. Please ask us if anything is not clear or if you would like more information.

Research Aims

We are interested in better understanding the effects of personality upon learning in golf putting. To do this we will be measuring your heart rate, muscle activity and swing pattern (i.e., your technique) while you practice putting.

Who Must We Exclude?

Heart rate monitors will be placed on the collarbones and lower rib cage. No one with injuries in this area should participate.

Where Will the Study Take Place?

The study will take place at the School of Sport, Health and Exercise Sciences, Bangor University. Please see the map at the end of this form.

How Long Will the Study Last?

The experiment should only last 1 hour.

What Will You Be Asked to Do?

You will be asked to complete a series of personality questionnaires and then putt 10 trails of five putts (50 putts in total)

Will You Compensate Me for My Time?

You will be paid a minimum of £5 for taking part.

Are There Any Risks Involved in Participating?

Nuprep skin prep gel improves conductivity and makes the heart rate reading more accurate. The cream does this by removing dead skin cells. For most participants this will not cause any discomfort. In the unlikely event that skin irritation occurs, the experiment will immediately stop. An antihistamine tablet or cream can be used to alleviate any irritation.

What If I Have Questions about the Project?

It is up to you to decide whether to take part or not. If you decide to take part, you are still free to withdraw at any time and without giving a reason. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form.

If you have any question regarding this research, please feel free to contact us. Thank you in advance for your participation, it is greatly appreciated.

Yours Sincerely,

Turki Alzahrani pep608@bangor.ac.uk
07454020444

Dr. Stuart Beattie s.j.beattie@bangor.ac.uk
Prof. Lewis Hardy l.hardy@bangor.ac.uk
Dr. Andrew Cooke a.m.cooke@bangor.ac.uk

The experiment will take place in the Padern Building, situated on point number 4 on the map below. Participants should arrive at the agreed time. A researcher will meet you at the entrance of George Building (number 5).

The School

PRIFYSGOL BANGOR UNIVERSITY

PRIFYSGOL BANGOR UNIVERSITY

Investigation: Examining the effects of personality upon learning golf putting

(Consent form)

Turki Alzahrani
Dr. Beattie, Dr. Hardy and Dr. Cooke

2017

Bangor University
SCHOOL OF SPORT, HEALTH AND EXERCISE SCIENCES

1	Title of project	**Investigation: Examining the effects of personality upon learning golf putting**
2	Name and e-mail address(es) of all researcher(s)	Turki Alzahrani pep608@bangor.ac.uk 07454020444 Dr. Stuart Beattie s.j.beattie@bangor.ac.uk Prof. Lewis Hardy l.hardy@bangor.ac.uk Dr. Andy Cooke a.m.cooke@bangor.ac.uk

Please initial the boxes

I confirm that I have read and understand the Information Sheet dated for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason, without my medical care or legal rights being affected. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason. If I do decide to withdraw I understand that it will have no influence on the marks I receive, the outcome of my period of study, or my standing with my supervisor or with other staff members of the School. ☐

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

I understand that I may register any complaint I might have about this experiment with Professor Tim Woodman, Head of School of Sport, Health and Exercise Sciences, and that I will be offered the opportunity of providing feedback on the experiment using the standard report forms. ☐

I agree to take part in the above study. ☐

Name of Participant ……………………………………………………………….

Signature ………………………………… Date …………………………………..

Name of Person taking consent…………………………………………………….

Signature …………………………………. Date …………………………………..

WHEN COMPLETED – ONE COPY TO PARTICIPANT, ONE COPY TO RESEARCHER FILE

Pictures of the experiments