TITLE
The acute effects of mental fatigue on cricket-specific performance

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The Acute Effects of Mental Fatigue on Cricket-Specific Performance

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The acute effects of mental fatigue on cricket-specific performance

Abstract

Ten professional and academy level cricketers (age = 21.1 ± 7.7 years; body mass = 77.1 ± 9.9 kg; stature = 184.9 ± 7.7 cm) were assessed on the effects of a mentally fatiguing task against an identical time frame completing a non-mentally fatiguing control protocol, when subsequently completing physical tasks relative to the sport of cricket. The purpose of this study was to investigate the effects of a mentally fatiguing task (30 minutes of a Stroop test) on sport-specific performance (run two test), hand-eye coordination (Batak lite) and intermittent running (YOYO test) among elite level cricket players. This was completed with a seven-day washout period between mentally fatiguing and non-mentally fatiguing tests. Visual analogue scales (VAS) were completed for levels of mental fatigue prior to the start of either mentally fatiguing or non-mentally fatiguing task, and immediately post task. Scores for motivation for the upcoming physical tasks were also recorded, as were rates of perceived exertion (RPE) immediately post yoyo test. There were statistical differences ($P < 0.05$) in the levels of perceived mental fatigue after the stroop test (M=46.6, SD= 5.854) compared to the control (M=16.6, SD= 3.565), the cricket run two test (M=6.2944, SD= 0.179) compared to the control (M=6.1948, SD= 0.175), the yoyo test (M=1732, SD= 401.796) compared to the control (M=1892, SD= 356.801), and the rates of RPE scores post yoyo (M= 8.25, SD= 0.635) compared to the control (M=7.05, SD= 0.369), whilst no statistical differences were found in the perceived fatigue levels prior to testing (M=14.4, SD=2.066) compared to the control (M=13.5, SD= 2.718), the motivation levels prior to the physical testing (M=82.2, SD= 4.392) compared to the control (M=82.2, SD= 6.321), and the batak lite scores (M=38.42, SD= 8.432) compared to the control (M=42.02, SD= 2.391). It was demonstrated that inducing a level of mental fatigue has acute performance consequences on physical tests relevant to the sport of cricket.

Keywords: *pre-frontal cortex, RPE, field sports, stroop*

Introduction

Mental fatigue from prolonged cognitive activity has been categorized as a psychobiological state and can be linked with reduced general levels of energy and feelings of tiredness (Boksem, Meijman & Lorist, 2005; Marcora, Staiano & Manning, 2009). It has also been shown to be progressive and cumulative in onset (Lal & Craig, 2001a). Common neural networks for physical and mental activation have been shown recently (Tanaka, Ishii, & Watanabe, 2014), inferring a connection between mental and physical fatigue. There is growing evidence to support the potential impact of elevated mental stress loads on physical performance (Marcora, Staiano & Manning, 2009; McCormick, Meijen & Marcora, 2015; Smith, Marcora & Coutts, 2015). This growing body of work offers a competing perspective on the previous work of Noakes (2004) and the proposed 'central governor model' (CGM). The CGM model argues that the brain triggers regulatory control over physical activity, and may limit skeletal muscle recruitment and generate a level of fatigue in high threshold physical situations to assist homeostasis and protect the body from potential injury. Based on this current evidence on the possible effects of mental fatigue, there is also now an increased interest in assessing the use of supplemental cognitive training during physical exertion to create a training effect from the increased 'total systemic load', therefore elevating an athlete's physical potential in environments where high levels of mental load, such as prolonged periods of concentration and focus, are required.

Studies investigating the acute effects of mental fatigue have often utilised different forms of physical activity, such as running or cycling, to identify performance decrements (MacMahon, Schücker, Hagemann & Strauss, 2014). However, the study of Smith et al. (2016) was the first to document the acute effects of mental fatigue on sports-specific skill, namely soccer, showing a reduction in running performance and increased perception of effort after a cognitively challenging task. In support of this, Badin, Smith, Conte, and Coutts (2016) reported that mental fatigue also had deleterious effects on sport-specific drills in soccer, with elevated levels of perceived exertion also demonstrated after strenuous physical activity. This information may be transferrable to other field sports, such as cricket.

In elite cricket, matches early in the county season may be mentally challenging, due to the sudden elevation in periods of prolonged concentration with minimal prior exposure during the six-month off-season. Players must endure extended periods of time spent standing in the outfield, focusing on the impending delivery or shot, or completing low levels of activity, such as walking and jogging. These are commonly interspersed with higher intensity activities, such as sprinting and jumping, diving and catching (Noakes & Durandt, 2000). This increased risk of mental fatigue may lead to athletes reducing effort levels in order to complete the physical task or maintain their anticipated perceived exertion, thus impairing performance (Brownsberger, Edwards, Crowther, & Cottrell, 2013; Edwards & Polman, 2013).

For cricketers in the UK, with overseas tours difficult to finance and home friendlies regularly weather affected, the lack of real-life, competitive practice can often leave players mentally underprepared for the upcoming fixtures. This may in turn contribute to elevation of levels of perceived fatigue during early matches by a lack of acclimatization to the specific conditions. Match fatigue, where prolonged bouts of concentration have had deleterious effects on skill qualities, has also been studied (Rampinini et al., 2008), but research is limited due to the difficulty in translating accurate laboratory assessment into a dynamic, field-based situation.

The higher levels of perceptual and cognitive abilities of elite athletes when compared to non-athletes have been discussed in literature (Miura, Nakata, Kudo & Yoshie, 2010; Yarrow & Krakauer, 2009). This increased ability to efficiently link the perceptual processing of information to the generation of a required action is often termed perception-action coupling. It is suggested that appropriate training enhances this and may be through enhanced development of neural substrates. When assessing elite level baseball players, Muraskin, Sherwin and Sajda (2015) found spatiotemporal differences from 200ms prior to the start of pitch trajectory and up to 700ms after. They also found an enhanced level of response inhibition in the elite group. This was represented by the athletes having an improved

perception of when not to play a shot, which would also correlate to cricket as a field sport. The skill of a batter is not only decided on how well certain shots are executed, but also by how well they can select balls not to hit, thereby increasing bowling spells, increasing potential for bowling errors, and ultimately capitalizing on the easier run making situations created. Muraskin et al. (2015) also discovered enhanced decision making skills, including response inhibition, when comparing baseball and basketball players to non-athletes. These findings would also suggest that any reduction in perception-action coupling, due to fatigue in the area of the brain responsible for these processes (most notably the frontal lobe), could have significant performance-related consequences to the athlete.

Mental fatigue has been repeatedly shown to affect attention in various ways, from visual selective attention and focus to time on task work (Brick, MacIntyre & Campbell, 2014; Faber, Maurits & Lorist, 2012), all of which would apply to a field sports scenario, such as soccer (Smith et al., 2016), baseball and cricket. The fronto-parietal network and the frontal lobe has been cited as the part of the brain that would sift relevant and non-relevant information and form the basis of attention, with factors such as fatigue and advancing age both compromising this ability to ignore non-relevant information and prioritise the relevant (Jurado & Rosselli, 2007; Lückmann, Jacobs, & Sack, 2014; Posner & Petersen, 1990; Wascher & Getzmann, 2014).

Another part of the prefrontal cortex, the anterior cingulate cortex (ACC), has also been shown to be affected by induced mental fatigue (Barch et al., 1997), with impaired decision making during effort noted in studies using animals (Rudebeck, Walton, Smyth, Bannerman & Rushworth, 2006; Walton, Bannerman, Alterescu & Rushworth, 2003). This may also give a physiological reasoning for the increased RPE scores evidenced after endurance activity once mental fatigue has been induced, shown by the work of Smith et al. (2016).

From a cricket skills perspective, this information would suggest that reaction times on skill tests, such as the batak lite apparatus (a free-standing piece of equipment with eight randomly lighting buttons that need to be pressed by the user as fast as possible), may be affected, and would correlate to both batting

reaction times, and catching requirements for the wicket-keeper and the players involved in the slip cordon. With ball speeds in cricket reaching over forty metres per second, it has been calculated that the ball will be in the right position for batters to strike it appropriately for around 2.5ms (Regan, Beverley & Cynader, 1979; Regan, 1992, 1997). For the slip cordon, issues such as no prior visual cues from the batter (as the slight deviation of the ball is an error rather than a deliberate shot) increase error potential, with such ballistic motor actions previously discussed as 'reflex' in nature and linked with reflexive stops from ice hockey goalkeepers (Regan, 1997). In baseball, ball speeds can be even higher than in cricket, meaning perceptual time frames for decision making can be as low as 150ms (Radlo, Janelle, Barba & Frehlich, 2001). Baseball bats being tubular, compared to the flat face of the cricket bat, will also increase the required accuracy of any spatio-temporal predictions made by the batter. Increased reaction times due to mental fatigue could therefore increase error rates in these key situations and affect team performance. Multiple runs, such as run twos or threes may also be affected, due to the judgment skills necessary for decelerating into the turn at an appropriate distance to maximize efficiency and also the turning mechanics themselves.

Activities that require a high level of concentration and attentional load (Nakagawa et al., 2013) have also shown a level of deactivation in the mid-brain. This disruption of normal activity, or compensatory effort, is believed to be evidence of suppression of the brains normal negative feedback system, which would in turn, under normal circumstances, initiate some form of recuperation (ideally rest) and therefore maintain homeostasis. A reduction of white matter volume in the midbrain of chronic fatigue sufferers (Barnden et al., 2011) may support this rationale, as long term suppression and disruption of normal function could lead to such physiological change. Safety legislation regarding helmet use in cricket has recently been upgraded in the UK, with much high profile discussion in the media. The players in the slip cordon (with the exception of the leg slip position) have not been added to the list of compulsory helmet use, along with the inner ring fielders. Any increase in fatigue-induced errors in

these key positions may however significantly increase injury risk. Impact injuries and fractures are already relatively common in these positions (Newman, 2003), which highlights the dangers further reductions in reaction times could pose.

Due to their proposed reliability as a marker of mental fatigue (Lal & Craig, 2002), Wascher et al. (2014) conducted electroencephalogram (EEG) studies and found significant changes in brain activity during the gradual onset of mental fatigue, noting regularly evidenced shifts towards lower frequency bands, such as delta, theta and alpha, with the higher frequencies of gamma and beta often reducing in their amplitude during mentally fatiguing tasks (Phipps-Nelson, Redman, & Rajaratnam, 2011; Zhao, Zhao, Liu, & Zheng, 2012; Lal & Craig, 2001b). Prolonged periods of time-on-task activities in particular trigger an increase in theta activity, which appears to be a reliable marker of mental fatigue onset. With significant periods of time-on-task activity, such as four days, broken down into three, two-hour periods per day spent either in the field or batting, cricket could clearly fall into the category of a mental fatigue-inducing environment.

Mental fatigue has also been shown to affect attention, and specifically a reduced capacity to ignore distractors (Hopstaken, van der Linden, Bakker, Kompier, & Leung, 2016). This also has implications for field sports, including cricket. With the rise in popularity of twenty20 cricket (where each team has 20 allotted overs each), potential distractors have expanded, from the obvious on-pitch ones of significant crowds, increased noise, television cameras, cheerleaders and music, to the subtler distractors of increased financial rewards and the pressures that accompany them, and contractual obligations and negotiations. These scenarios could all contribute to either a visible reduction in performance, or an automated regulation of physical performance as a consequence of increased 'total systemic load', which would still qualify as a performance decrement.

Attentional involvement has been linked closely to intrinsic motivation (Abuhamdeh & Csikszentmihalyi, 2012) and also the enjoyment of goal-specific activities (Csikszentmihalyi, 1975;

Jackson & Csikszentmihalyi, 1999). Intrinsic motivation has been defined as the engagement of an activity simply for the pleasure derived from that participation (Deci & Ryan, 1985; Lepper, Greene, & Nisbett, 1973). Any reduction in attention involvement due to fatigue could potentially begin to negatively alter the individuals' enjoyment of the tasks, their intrinsic motivation for the tasks, and also their perceptions of competence in the tasks. This progressive reduction of involvement and motivation could therefore begin to manifest itself in increased errors and further perpetuating the cycle of disengagement from the skill-specific tasks, leading to either an ongoing cycle or an increased volume of reduced performance qualities in both practice and match situations.

Based on the evidence provided, it was hypothesised that a mentally fatiguing task prior to any physical activity would increase the rate of perceived effort and reduce time to exhaustion. Mental fatigue may also acutely affect attention and the ability to ignore irrelevant distractors, co-ordination and judgment skills, which may also impact on tasks such as catching balls at high velocities or judging a turn when batting to efficiently execute multiple runs such as run twos or run threes.

The purpose of this study was to investigate the acute effects of a mentally fatiguing task on cricket-specific physical tasks, such as specific sprint tests, repeat sprint ability, reaction times and hand-eye co- ordination. It was further hypothesised that the introduction of a mentally fatiguing task would negatively affect times for decision making and co-ordination, sprint tests and repeat sprint ability.

The findings of this study are likely to increase both the players' and the coaches understanding of the short-term effects of mental loads on multiple aspects of cricket- specific performance, potentially leading to improved coping strategies, or stimulate tactical adjustments to elicit an improved team outcome.

Methods

Participants

Ten male participants (age = 21.1 ± 7.7 years; body mass = 77.1 ± 9.9 kg; stature = 184.9 ± 7.7 cm) provided informed consent. All forms were approved by the St Mary's University Ethics Committee. Participants were selected from both the academy and professional squads at Somerset county cricket club (SCCC), based in Taunton, Somerset, UK, while they were taking part in the SCCC off-season winter training programme. All participants had a minimum training age of two years, all of which has been completed with SCCC. This therefore offers a level of consistency, along with considerable familiarity with the physical tasks utilised in the study beyond the stated two years of training age, due to the majority of the tests being implemented throughout the county age group structures from under twelve level. This familiarity is also likely to minimize any variation due to learning effects or a lack of understanding. Steps were made to ensure that participants fully understood that their participation was voluntary and that they may opt out at any time, without detriment to them.

Study design

To investigate the effects of mentally fatiguing tasks on cricket-specific performance, a randomized, cross-over design was used. The independent variable was the condition that preceded the cricket-specific tasks and comprised two levels (fatiguing or non-fatiguing). The participants were randomly allocated into one of the two conditions using a random number generator on Microsoft Excel and then re-tested seven days later with the other preceding condition (see below for further detail on the mentally fatiguing conditions). There were three dependent variables, designed to measure cricket specific performance. A 'cricket run two test' (a test of sprint speed with a bat and 180 degree change of direction), a yoyo intermittent recovery test (yoyo IR1) level 1 (Bangsbo et al., 2008) and a cricket-specific hand-eye co-ordination test (Gierczuk & Bujak, 2014).

Procedures

Participants arrived at the testing facility (SCCC) at the same time of day (10 am), in a well-hydrated state. All participants were instructed to avoid consumption of alcohol or caffeinated products, as well as avoiding strenuous exercise, in the 48 hours before testing. Various supplements often used in professional sports, such as branched-chain amino acids and creatine, have been shown to have beneficial effects against mental fatigue (Blomstrand, 2006; Durkalec-Michalski & Jeszka, 2016; Kreider et al., 1998; Newsholme, Blomstrand & Ekblom, 1992) and could possibly affect accuracy of the data collected. For this reason, all participants were instructed to discontinue use of any sports supplements from 7 days prior to the first trial through to the end of the second trial.

A familiarization session took place (visit 1) one week prior to the experimental conditions, where participants were instructed on how to perform each of the tests and given chance to practice and ask questions.

At visit 2 the cricket specific tasks were completed, within two minutes of completion of either the mentally fatiguing or non-mentally fatiguing tests. After a standardised warm-up, the tests followed the order of the run two test, the batak lite test and the yoyo IR1 test. This allowed for a more substantial recovery between the two physical tasks, and the time frame created became similar to that when testing each squad throughout the season (normally thirty to forty minutes). A period of five minutes was allowed between tests, to accommodate toilet breaks and transition to the part of the building where the next test was due to be performed. The rooms used for the mentally fatiguing tests, non-mentally fatiguing tests, and batak lite test are adjacent to the indoor school where the physical tests were performed. This was consistent between tests on all testing days.

The cricket run two test is an ECB standard test, and is defined as the ability to run one length of the cricket pitch (17.68m) with a bat in either left or right hand, run the bat in over the crease line whilst turning and sprint back for one length (ECB revised testing protocols, 2015). Although primarily a physical task, which according to various research (Martin, Thomson, Keegan, Ball, & Rattray, 2015;

Pageaux, Marcora, & Lepers, 2013) should not be directly affected by the mentally fatiguing task, there is a skill aspect to the drill, namely the turn and the execution of it. Precise timing of the decelerating steps leading into the turn, not excessively running the bat over the crease-line before re-accelerating in the opposite direction will all be required to facilitate a quality run two. As skill-specific qualities have been shown to be affected by mental fatigue (Smith et al., 2016), any mental fatigue present during the test could have potentially affected one of these skill-dependent variables and increase times to completion.

Infra-red timing gates (Brower timing gates, Brower TC athletic timing system, Brower timing systems, UK) were set up at either end of the 17.68 m to measure a time split of each sprint. All participants performed five sprint attempts, with two minutes' recovery between attempts, and each time being recorded by the wireless transmitter of the timing gate The average sprint time was recorded after testing was complete.

The hand-eye co-ordination test was performed 5 minutes later, using the batak lite reaction test apparatus (Batak Lite model, Batak.com, UK). The apparatus has various settings and time challenges, with the two-minute test and the thirty second test previously validated as measurement tool for reaction times and hand-eye co-ordination (Gierczuk & Bujak, 2014), with sufficient levels of reliability. The thirty second test was used in this study. This test required the participant to tap as many of the eight randomly lighting buttons as possible in the time frame, which in this case was five 30 second attempts (Gierczuk & Bujak, 2014), with 2 minutes allowed between attempts. A score was awarded for each light being tapped and summated at the end. Total scores from each attempt were recorded. This piece of equipment has been used previously within county cricket to support hand-eye co-ordination and reaction time training for the various skill sets, such as batting, keeping wicket or standing in the slip cordon. This is often only for warm up purposes or with age group practice sessions however, as an alternative to conventional coach driven methods.

The final task was the yoyo intermittent recovery test level 1 (Bangsbo et al., 2008). This was a progressive shuttle run of twenty metres, where the participants ran between two cones, placed twenty metres apart, at a tempo dictated by an external 'bleep' sound until they failed to maintain the correct movement rate. The total distance that the participant covered (number of shuttles x 20 m) was recorded. Reliability studies have been conducted previously for the level one version (Thomas, Dawson, & Goodman, 2006). This is currently the preferred tool to measure aerobic capacity within cricket, due to the repeated turning requirements and similarities in distance per shuttle to cricket pitch lengths (ECB revised testing protocols, 2015), and is a well-known test to the subjects. The intermittent yoyo recovery test level 1 is a publically available piece of testing equipment.

After a 7-day washout period, this process was repeated (visit 3), under the other experimental condition. A period of no more than two minutes was permitted between the preceding mentally fatiguing or non-mentally fatiguing tasks and the cricket-specific performance tests.

Mentally Fatiguing Task

The mentally fatiguing task used was a 60 second stroop test, repeated for 30 minutes (i.e. 30 times). The stroop test required participants to select the colour of a word, when it was printed in a colour not necessarily denoted by the name (i.e. selecting 'red' when the word 'green' is printed in red) under timed conditions. This caused an interference effect known to be cognitively demanding for participants. Multiple repetitions of similar tests have been used previously to induce mental fatigue prior to soccer activities (Smith et al., 2016; Badin, Smith, Conte, & Coutts, 2016). The version of the stroop test used was part of an app-based program called 'Brainiversity'. The version 1.0 for mac was used, and is freely available for purchase for computers, tablets and phones. At the end of the test the scores were recorded to monitor the level of fatigue experienced by participants prior to the trial. There was a two second delay before the results appear on screen. Participants were asked to turn around during this delay to prevent scores from being seen and increasing any potential interference.

Participants were told that the final scores for the group would be put up on the display board in the gym, thus creating a level of social comparison among their peers, help to ensure full adherence and also limit boredom.

Rauch and Schmitt (2009) found a level of fatigue in cognitive control in participants within fifteen minutes. By comparing the participants' performance in the first and second fifteen attempts, the efficacy of the app based version to adequately induce mental fatigue could be assessed, and potentially support further use in other studies.

In the non-fatiguing condition, the participants were asked to read magazines of their choice for thirty minutes. The magazines were pre-selected to provide some level of casual interest to the reader, whilst being relatively neutral (i.e. Various sports magazines) in content (Smith et al., 2016).

VAS scales for pre-physical assessments

A 100mm visual analogue scale (VAS) was used to collect the participants level of mental fatigue for the stroop test or the reading treatment. Lines were anchored at one end with 'none' and the other with 'maximal'. Participants were asked to mark on the line their perceived state of fatigue both before and after each of the stated tests, with marks being measured from left to right and recorded. They were also asked to mark their perceived level of motivation for the upcoming physical tests. All three marks were drawn one scale, and were numbered one, two and three in order to distinguish pre mentally fatiguing test, post mentally fatiguing test, and motivation.

RPE data

The CR-10 Borg scale (Borg, 1982, 1998) was used post yoyo test in both assessments to evaluate the participants. This was favoured over the 15 point (6-20) scale used by Smith et al. (2016), when assessing perceived fatigue, as the participants have experience of this method, have used it for a period of time and therefore required no memory anchoring for it.

Participants were required for no more than 120 minutes on each of the three visits of testing. As all participants were part of either the professional or academy squads at Somerset CCC, timings were primarily based around off-season training times to reduce any further impact. Testing took place in the Centre of Excellence indoor facility at SCCC.

Statistical Analyses

Pairwise differences between the dependent variables were identified by using paired *t*-tests. Significance for the tests was set at $P < 0.05$, and all statistical analyses were conducted using SPSS 22. All data are presented as means $\pm$ sd.

Results

A paired samples t-test was conducted to compare the VAS scores for perceived levels of mental fatigue immediately prior to commencing the mentally fatiguing task in both the mentally fatigued and the non-mentally fatigued control conditions. There were no significant differences in the scores for mentally fatigued (M=14.4, SD=2.066) and non-mentally fatigued (M=13.5, SD= 2.718) conditions; t (9) = 0.927, p = 0.378 (Figure 1).

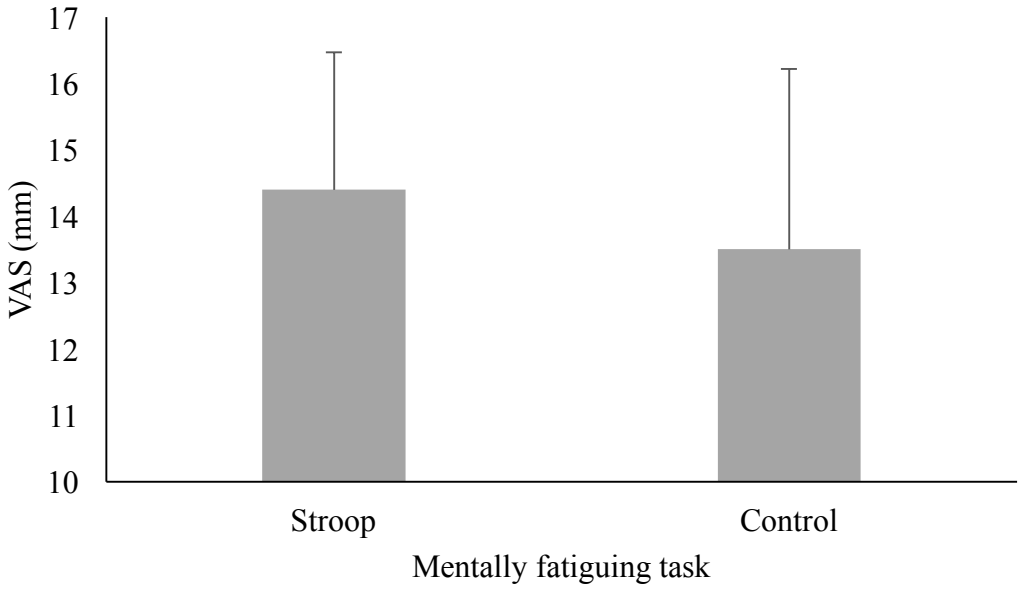

Figure 1. Comparison of perceived levels of mental fatigue prior to mentally fatiguing task.

A paired samples t-test was conducted to compare the VAS scores for perceived levels of mental fatigue immediately post completion of the mentally fatiguing task in both the mentally fatigued and the non-mentally fatigued control conditions. There were significant differences in the scores for mentally fatigued (M=46.6, SD= 5.854) and non-mentally fatigued (M=16.6, SD= 3.565) conditions; t (9) = 12.158, p = 0.000 (Figure 2).

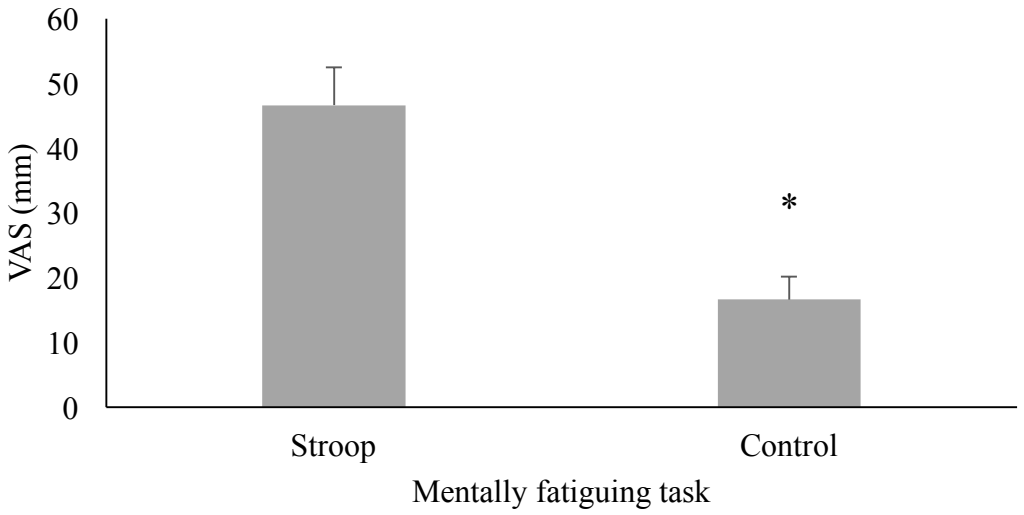

Figure 2. Comparison of perceived levels of mental fatigue immediately post mentally fatiguing task. * = significantly different from the post-mental fatigue scores.

A paired samples t-test was conducted to compare the VAS scores for perceived levels of motivation prior to commencing the physical tasks in both the mentally fatigued and the non-mentally fatigued control conditions. There were no significant differences in the scores for mentally fatigued (M=82.2, SD= 4.392) and non-mentally fatigued (M=82.2, SD= 6.321) conditions; t (9) = 0, p = 1.000 (Figure 3).

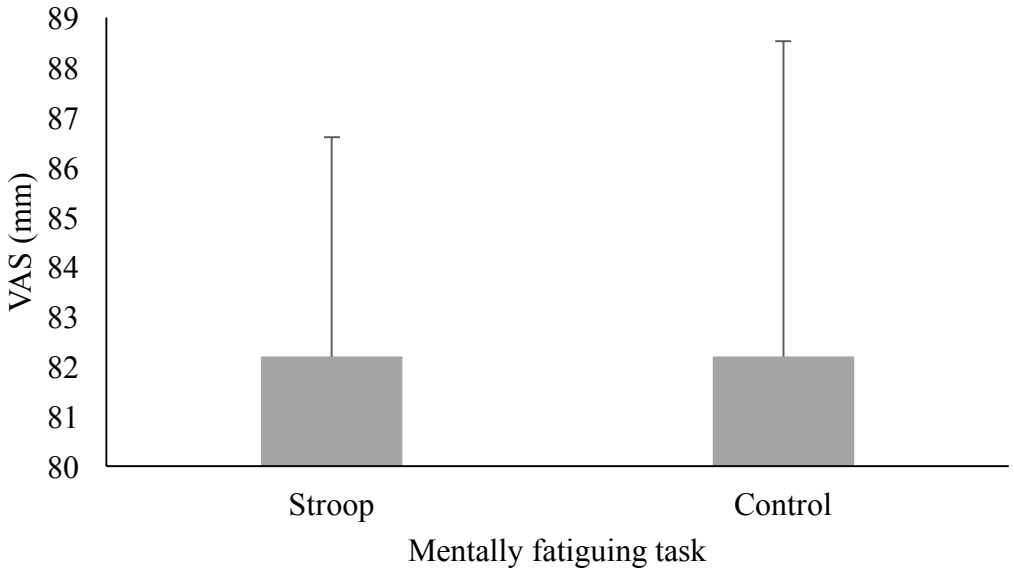

Figure 3. Comparison of perceived levels of motivation immediately prior to yoyo test.

A paired samples t-test was conducted to compare the scores for the cricket run two test in both the mentally fatigued and the non-mentally fatigued control conditions. There were significant differences in the scores for mentally fatigued (M=6.2944, SD= 0.179) and non-mentally fatigued (M=6.1948, SD= 0.175) conditions; t (9) = 4.39, p = 0.002 (Figure 4).

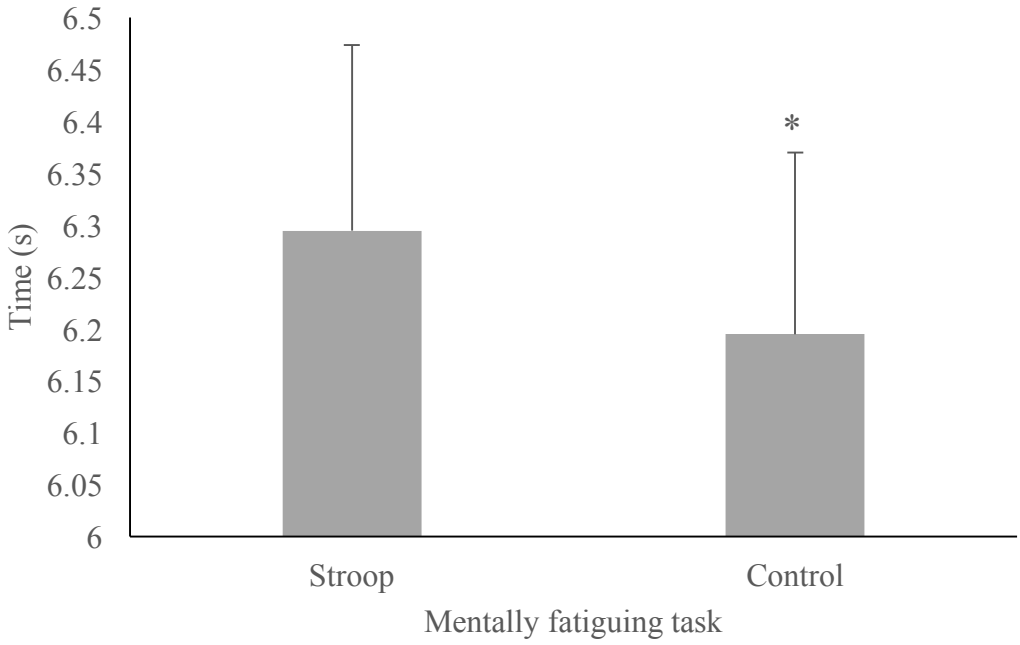

Figure 4. Comparison of cricket run two scores.

* = significantly different from the post-mental fatigue scores.

A paired samples t-test was conducted to compare the scores for batak lite test in both the mentally fatigued and the non-mentally fatigued control conditions. There were no significant differences in the scores for mentally fatigued (M=38.42, SD= 8.432) and non-mentally fatigued (M=42.02, SD= 2.391) conditions; t (9) = -1.631, p = 0.137 (Figure 5).

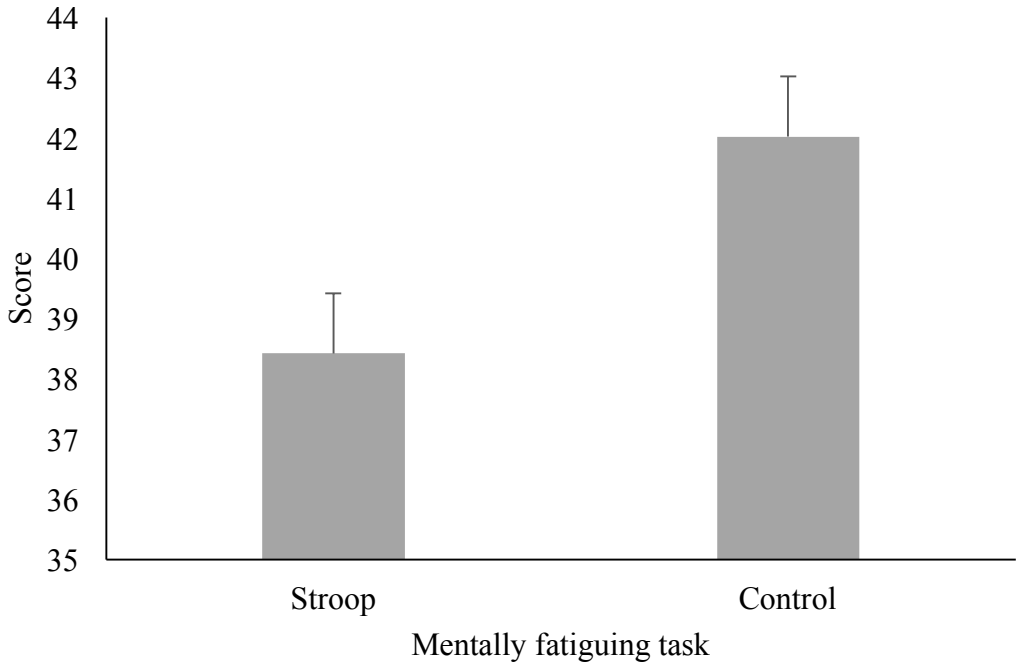

Figure 5. Comparison of batak lite 30 second test scores.

A paired samples t-test was conducted to compare the scores immediately post completion of the yoyo IR1 test in both the mentally fatigued and the non-mentally fatigued control conditions. There were significant differences in the scores for mentally fatigued (M=1732, SD= 401.796) and non-mentally fatigued (M=1892, SD= 356.801) conditions; t (9) = -2.739, p = 0.023 (Figure 6).

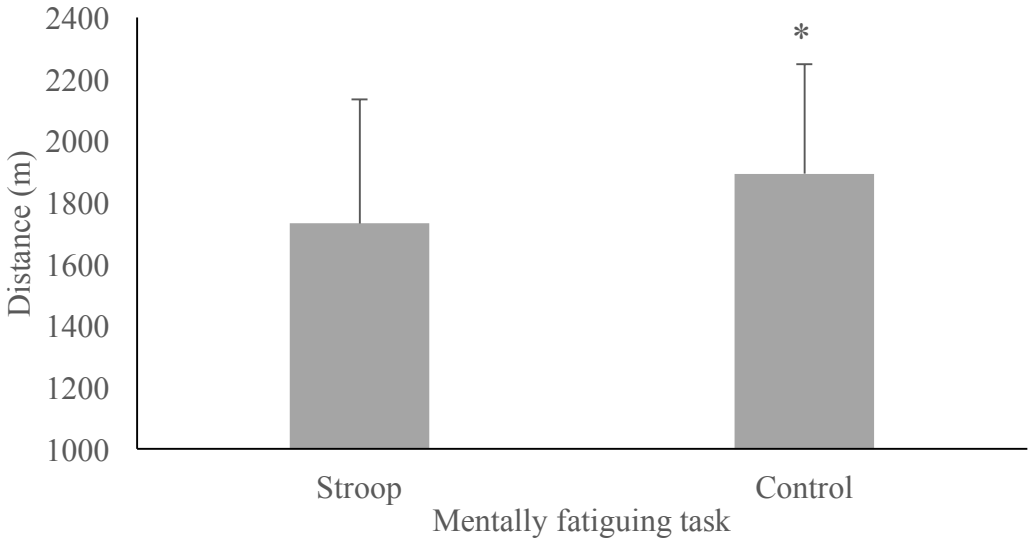

Figure 6. Comparison of yoyo IR1 test scores.

* = significantly different from the post-mental fatigue scores.

A paired samples t-test was conducted to compare the perceived rate of exertion scores immediately post completion of the yoyo test in both the mentally fatigued and the non-mentally fatigued control conditions. There were significant differences in the scores for mentally fatigued (M= 8.25, SD= 0.635) and non-mentally fatigued (M=7.05, SD= 0.369) conditions; t (9) = 4.811, p = 0.001 (Figure 7).

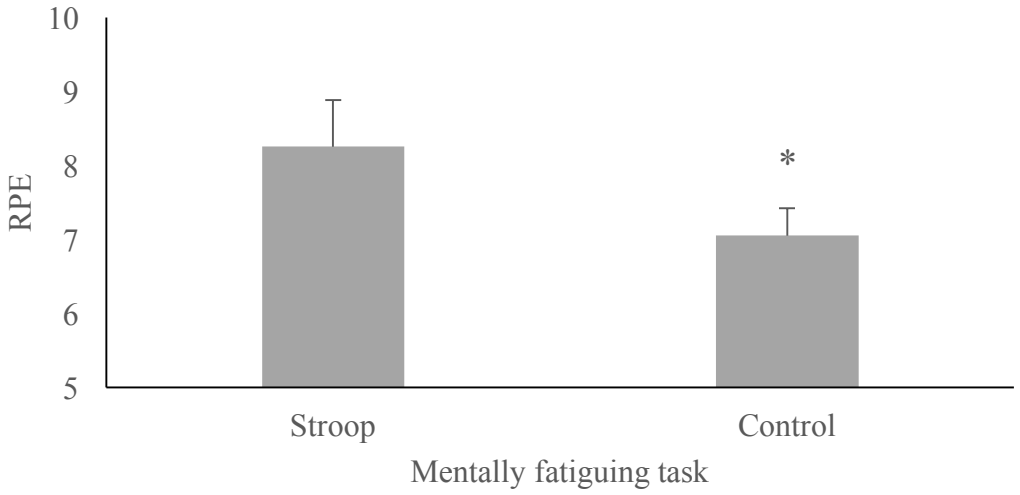

Figure 7. Comparison of RPE scores post yoyo test.

* = significantly different from the post-mental fatigue scores.

Discussion

The primary findings of this study were that the introduction of a mentally fatiguing task significantly affected performance markers for the cricket run two test and the yoyo intermittent recovery test. The deterioration in the stroop test scores (1st 15 attempts = 29.44 ± 4.07; 2nd 15 attempts = 26.83 ±5.34) suggests the thirty-minute app-based stroop test was a valid method of inducing mental fatigue, unlike the work of Pageaux, Lepers, Dietz, and Marcora (2014), who failed to generate increases in mental fatigue after a computer-based stroop test. This would suggest it is a viable option for use in further research to expand knowledge of the acute effects of mental fatigue. The comparisons between the first and second fifteen attempts also support the work of Rauch and Schmitt (2009), in that a level of mental fatigue can be generated within fifteen minutes.

The data collected from the stroop test was validated further when the VAS were collated. Markers taken immediately after the stroop test shows a significantly increased perception of mental fatigue when compared to scores taken after thirty minutes of reading, which has also been noted in other research (Badin et al., 2016). Motivation levels for the upcoming physical tests however, were not significantly affected. This unexpected finding may have been due to the existing relationship between the participants and the primary researcher, which may have resulted in participants being 'pre-programmed' to report minimal reductions in motivation for physical tasks. The scores may also have been collected too early to generate an honest appraisal of the level of motivation from the participant, and delaying this marker until some point further into the physical tasks may have elicited a different result. The length of the mentally fatiguing task may also have been insufficient to generate any significant intrinsic motivational change in a group of highly motivated elite cricketers, despite creating a level of mental fatigue. Further research into this field would be beneficial, and help to clarify these findings.

Times for the cricket run twos were significantly increased across the group after the mentally fatiguing task, compared to control scores. This would suggest that the mental fatigue induced a level of impaired judgment regarding various factors involved, such as the timing of the required deceleration prior to the turn, how far over the crease to run the bat in and the actual turning mechanics themselves. The size of the average increase is also of a level that would have implications for professional cricket. With typical velocities for batters running between the creases being between four and five metres per second (Noakes & Durandt, 2000), a reduction of one tenth of a second could easily result in a batsman failing to run his bat over the crease and therefore being given out.

Previous studies (Martin, Thomson, Keegan, Ball, & Rattray, 2015; Pageaux, Marcora, & Lepers, 2013) have suggested that purely physiological parameters, such as maximum voluntary contraction (MVC) would not be affected by increased levels of mental fatigue. Others (Smith, Marcora & Coutts, 2015; Pageaux, Marcora, & Lepers, 2013) found that brief, high intensity efforts (defined as between 70-100% intensity) lasting no more than a few seconds were not affected by mental fatigue, suggesting that neuromuscular fatigue would be the primary fatigue marker. This study did not completely validate those findings further. This could have been done with the inclusion of a battery of straight line sprints in conjunction with the cricket run twos. This would have given a comparison of a more discrete performance test, such as sprinting, against another sets of sprints over a similar distance (namely crease to crease), but with the added requirements of judging appropriate deceleration, running the bat over the crease enough to elicit a genuine run but not excessively, and to finally make the fine motor adjustments necessary to turn efficiently and re-accelerate in the opposite direction. It is suggested that any further research into the area should include some form of testing to clarify this aspect further, and potentially add further support to the psychobiological model (Marcora, 2008; Marcora, Bosio & de Morree, 2008).

Scores for the repeated batak lite 30-second test were reduced after the mentally fatiguing task, when compared to the control task, but were not found to be statistically significant. A possible explanation

may be due to the large standard deviation noted from the participants. This would suggest that a larger sample group may have found different results. Further research would be highly beneficial in light of the findings to increase information on the effects of mental fatigue, as any reduction in the qualities of either reaction times or hand-eye co-ordination during match play may have implications for players in close catching positions, such as wicket-keeping or the slip cordon (positioned adjacent to the wicket-keeper), with an increased likelihood of dropped catches from the elevated response time.

Increased RPE scores and reduced physical performance in the yoyo test after the mentally fatiguing task when compared to the control test appears to validate previous research (Smith et al., 2016; Smith, Marcora & Coutts, 2015; MacMahon, Schücker, Hagemann & Strauss, 2014). An elevation in the perceived effort required to complete a given task elicited a reduced physical response when compared to a control. It also in part supports the psychobiological model proposed by Marcora, Bosio, and De Morree (2008) and Marcora and Staiano (2010) when discussing limiting factors to endurance performance, in that any deterioration in performance markers may be more related to the participants disengagement from the task due to an elevated perception of their own required effort, and therefore the inherent difficulty of the task. The potential reduction in efficient turning mechanics may also play a part in an accumulated reduced capacity for repeat sprint ability. Further research may benefit in using a method that does not include any turning requirements to assess endurance qualities in field sports.

No physiological parameters, such as heart rate (HR) and other physiological variables such as blood lactate were measured or monitored. This may have increased the validity of the findings, although other research discovered no significant relationships between these variables and mental fatigue (Marcora, Staiano, & Manning, 2009; Pageaux, Marcora, Rozand, & Lepers, 2015).

A larger cohort of both professional cricketers and academy level cricketers would have been beneficial, not only to increase robustness of results and reduce potential errors (as mentioned when discussing the reaction time test), but also to evaluate the potential of a residual adaptation or training

effect from the high number of matches completed with prolonged bouts of attention and concentration from the professional players, when compared to the academy players. The current study was completed in March, immediately prior to the commencement of the UK cricket season, and potentially where any residual training effects from the previous season would be at their lowest. Research completed in October, immediately after the season ends, could highlight any training effect and adaptation from the rigours of a typical county cricket season.

Development of a mentally fatiguing protocol could potentially expand this training effect, be utilized progressively through the winter period in order to optimally condition cricketers to the total systemic load they will be required to tolerate during the season, and become a vital addition to the current skills and physical training regimen. This would also potentially highlight an opportunity to add mentally fatiguing protocols to any academy programme in order to enhance this quality and reduce spikes in mental fatigue during early season matches and support a smoother transition from the amateur academy stages to that of full professional sport, where total match volume is higher in comparison. Timing of any additional potentially mentally-fatiguing tests would need to be carefully planned, and should cease well in advance of any upcoming matches to ensure players do not enter the game in an already fatigued state. There are often significant levels of player downtime during a typical batting innings, in which players may partake in potentially mentally fatiguing tasks, such as crosswords, sudoku's, or games on tablets and smartphones. The results of this study shows that these tasks could potentially induce a level of mental fatigue that may be detrimental to the upcoming physical tasks, such as batting, or bowling and fielding after a declaration or loss of all ten wickets. Further monitoring or periodic restriction of these mentally fatiguing tasks at key times may well be prudent in light of this study in order to minimize this risk and maximize performance potential.

Conclusion

Mental fatigue, induced by an app-based stroop test for thirty minutes, acutely affected cricket-specific performance in both professional and county academy level cricketers. Hand-eye co-ordination and reaction times, as measured by repeated attempts on the batak lite apparatus, sprinting and turning abilities, as measured by repeated attempts of cricket run twos, and time to exhaustion, as measured by the yoyo intermittent recovery test, were all reduced after the mentally fatiguing test when compared to a non-fatiguing condition of reading magazines of relevant interest for the same period of time. The physiological reasons for these occurrences may be multi-faceted for each protocol, such as impaired function of the prefrontal cortex of the brain, leading to reduced attention, reduced processing capacity and judgment of distance, reduced perception-action coupling, or an increased level of perceived fatigue promoting early cessation of endurance activity, but the culmination is likely to have implications for cricket matches in the UK, and during the early part of the season in particular, where a limited capacity to tolerate prolonged periods of attention and concentration may acutely affect performance, and therefore reduce a teams collective potential for elite high performance throughout the UK cricket season.

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Word Count – 6044 words, including figures.

Appendix 1. Signed ethical approval form.

St Mary's University Twickenham London

cc Mark Waldron

Darren Veness (SHAS): 'The effect of mental fatigue on cricket-specific performance'

9 February 2016

Dear Darren
University Ethics Sub-Committee
Thank you for re-submitting your ethics application for consideration.
I can confirm that all required amendments have been made and that you therefore have ethical approval to undertake your research.

Yours sincerely

Dr Conor Gissane
Chair of the Ethics Sub-Committee

Appendix 2. Study information sheet.

Study information sheet

Section A: The Research Project

1. Title of project

   The effect of mental fatigue on cricket-specific performance

2. Purpose and value of study

   The purpose of the study is to assess the effects of a mentally fatiguing task on physical tasks that will relate to cricket, such as your endurance capabilities (measured by a yoyo test), cricket specific speed (measured by a run 2), and a cricket-specific hand eye co-ordination task (such as the BATAK 30 second test).

   The primary value in this study will be to decide whether mentally fatiguing tasks influence match preparation, pre-season preparation and in-match situations for cricketers.

   This may or may not then lead to developing a strategy to use the information found to improve and enhance cricket-specific preparations.

3. Invitation to participate

   Please take this document as an invitation to participate in this research.

4. Who is organising the research

   Darren Veness, the head of strength and conditioning at Somerset County Cricket Club, will be organising all aspects of the research as part of his MSc degree at St Mary's University.

5. What will happen to the results of the study

   The results will be compiled and assessed for any potential benefit to cricket-specific performance, and stored electronically on the St Mary's University servers. You will receive written notification of the outcomes. These results may then lead to further investigations into the field.

6. Source of funding for the research

   Any costs incurred during the research will be met by the research leader, Mr Darren Veness.

7. Contact for further information

   Mr Veness can be contacted at any point, via 125562@live.stmarys.ac.uk. Alternatively, you may contact his supervisor, Dr Mark Waldron, via;

   St. Marys University
   Waldegrave Road
   Twickenham
   Greater London
   TW1 4SX
   0208 240 4000

Section B: Your Participation in the Research Project

1. Why you have been invited to take part
   You have been invited to take part due to your inclusion in either the Somerset CCC professional squad, the Somerset CCC academy squad, or the Somerset CCC emerging player programme. This means you have completed the physical tasks required on multiple occasions, meaning any interference, be that positive, negative, or negligible, from the additional mental tasks may be more recognisable. You are also the individuals most likely to benefit from any positive outcomes of the study.
2. Whether you can refuse to take part
   You may refuse to take part, by either discussing with Darren Veness at any point either in person or via the contact details provided, or by completing the refusal section on the consent form provided.
3. Whether you can withdraw from the project at any time, and how
   You may withdraw at any point from the study with no penalty whatsoever, by either discussing with Darren Veness at any point either in person or via the contact details provided, or by completing the refusal section on the consent form provided.
4. What will happen if you agree to take part (brief description of procedures/tests)
   If you agree to participate, you will be required to undertake three physical tasks, comprising multiple run twos, a yoyo test, and a hand-eye co-ordination test using the BATAK equipment. This will be repeated 7 days later, but with an additional 30 minute mentally challenging task, completed on a laptop computer.
5. Whether there are any risks involved (e.g. side effects) and if so, what will be done to ensure your wellbeing/safety.
   The risks involved in the study are likely to be similar to those found when performing the physical tasks alone. Any side effects are likely to be fatigue related and would likely result in an earlier cessation of activity rather than any increased risk of injury. This does not mean that there are no risks at all, and consultation with the medical team at Somerset CCC is advised if there are any doubts on the risks involved in participation. Any decisions reached by the medical team would be respected by the primary researcher, Mr Darren Veness.
6. Agreement to participate in this research should not compromise your legal rights if something goes wrong.

7. Whether there are any special precautions you must take before, during or after taking part in the study.
   Participants will be expected to begin all assessments in a well hydrated state and with no pre-existing conditions that may compromise either the study or more importantly, the well-being of the participant.
8. What will happen to any information/data/samples that are collected from you
   All information will be collected by Mr Darren Veness to collate and finally to produce documented evidence of any individual and group outcomes. This information will be stored electronically on the St Mary's University servers, and accessible to each applicant at any time during the study and after all reports have been written.
9. Whether there are any benefits from taking part
   There may be benefits that come from participation in the study. The connections between mental and physical fatigue in field sports, and with cricket in particular, are relatively unknown. Any

additional information discovered from the study may enhance your understanding of the game and give a deeper understanding of the preparation required to fully engage in the sport.

10. How much time you will need to give up to take part in the project
All testing will be conducted during your allocated time at Somerset CCC, and will therefore have minimal additional impact from you time-wise.

11. How your participation in the project will be kept confidential
All information will be stored according to Somerset CCC Science and Medicine department confidentiality requirements. By signing your contracts with the club, you have already signified that this is an acceptable level of security. If there are any issues that require discussion, then contact Mr Veness, either in person or by using the contact information already provided.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

Appendix 3. Consent form.

St Mary's University Twickenham London

Name of Participant: _____

Title of the project: The effect of mental fatigue on cricket-specific performance

Main investigator and contact details: Darren Veness, 125562@live.stmarys.ac.uk.

Members of the research team: Darren Veness

1. I agree to take part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.
2. I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.
3. I have been informed that the confidentiality of the information I provide will be safeguarded.
4. I am free to ask any questions at any time before and during the study.
5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print)……Signed……..Date……

Name of witness (print)……..Signed……..Date……

If you wish to withdraw from the research, please complete the form below and return to the main investigator named above.

Title of Project: _____

I WISH TO WITHDRAW FROM THIS STUDY

Name: _____

Signed: _____ Date: _____