The Use of Game-Based Training to Provide a Match-Specific Environment for Cricket Players

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Statement of Originality

The thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University’s Digital Repository, subject to the provisions of the Copyright Act 1968.

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Acknowledgement of Collaboration

I hereby certify that the work embodied in this thesis has been done in collaboration with other researchers, or carried out in other institutions. I have included as part of the thesis a statement clearly outlining the extent of the collaboration, with whom and under what auspices.

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We, Ben Dascombe and Rob Duffield attest that the research completed within this thesis by the candidate William Vickery, was completed in collaboration with the following organisations:

- University of Technology, Sydney
- Australian Institute of Sport, Canberra
- Cricket Australia, Albion

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Supervisor: Rob Duffield (PhD)  Date Signed
Acknowledgement of Authorship

I hereby certify that the work embodied in this thesis contains published papers of which I am a joint author. I have included as part of the thesis a written statement, endorsed by my supervisors, attesting to my contribution to the joint publications.

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We, Ben Dascombe and Rob Duffield attest that Research Higher Degree candidate William Vickery was a contributor to the conception, design, writing and revision of the previously mentioned publications.

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Abstract

Cricket coaches have historically relied on isolated training practices such as net-based sessions and centre-wicket (CW) simulations to develop match-specific skills. However, such training modes may lack skill-specific application or be of insufficient intensity compared to a match. Recently, a small-sided games (SSG) approach has been designed for cricket (termed Battlezone [BZ]); to concurrently develop the conditioning profile and technical abilities of players. This thesis examined the physiological, physical and technical demands of cricket players during various cricket training formats and match-play. The application of game-based training within the sport of cricket, particularly BZ, may provide a unique training environment for improving a player’s conditioning and skill profile which can be transferred into match-play.

In recent times, the physical demands of athletes have been quantified using individual global positioning system (GPS) devices. In order to complete the current research, the accuracy of the GPS devices used to quantify physical demands were examined. Two male participants (age: 25.5 ± 0.7 yr; height: 1.75 ± 0.01 m; body mass: 74.0 ± 5.7 kg) completed ten repetitions of drills replicating movements of cricket activities (as well as tennis and field-based sports), whilst wearing two 5, 10 (MinimaxX) and 15 (GPSports) Hz GPS devices. The GPS devices were compared to a 22-camera VICON system. No significant differences were reported ($p > 0.05$) between the GPS devices and VICON system for the majority of distance and speed measures. The results also showed no improvements in accuracy with increases in the sampling rate.
of the GPS devices when compared to VICON ($p > 0.05$). The co-efficient of variation (CV) for the 5 and 15 Hz devices for distance and speed measures ranged between 3-33%, with increasing variability evident in higher speed zones. When examining the reliability of the devices, a low level of inter-unit reliability ($r = -0.35–0.39$) was reported for the majority of measures. Based on these results, the GPS devices demonstrated a low to moderate level of inter-unit reliability for distance and speed measures during high-speed straight line running, multi-direction movement patterns and unstructured movements.

By applying the results demonstrated in the previous study, Study 2 compared the physiological, physical and technical demands of elite cricket players during traditional cricket training (TCT) sessions (net sessions and fielding drills) ($n = 26$), CW simulations ($n = 5$) and One-Day (OD) matches ($n = 5$). During all training and match-play, heart rate (HR), movement patterns and rating of perceived exertion (RPE) were recorded from 42 cricket players (age: $23 ± 4$ yr, height: $1.86 ± 0.07$ m, body mass: $85.8 ± 8.5$ kg). Quantification of technical skill involvements was performed via post hoc video analysis. Medium-fast bowlers demonstrated similar physiological (mean HR [HR$_{\text{mean}}$]: $148 ± 16$ b·min$^{-1}$; $148 ± 9$ b·min$^{-1}$) and physical (mean speed: $82 ± 13$ m·min$^{-1}$; $77 ± 28$ m·min$^{-1}$) responses during the TCT and OD matches, respectively. By comparison, CW simulations were characterised by a decreased physiological (HR$_{\text{mean}}$: $129 ± 17$ b·min$^{-1}$) and physical (mean speed: $64 ± 13$ m·min$^{-1}$) intensity. Batsmen were placed under greater physiological and physical demands from OD matches when compared to either TCT or CW training format. Further, a higher HR$_{\text{mean}}$ (TCT: $137 ± 14$ b·min$^{-1}$; CW simulations: $148 ± 12$ b·min$^{-1}$; OD match: $152 ± 13$ b·min$^{-1}$) was reported.
b·min⁻¹) and mean speed (TCT: 25 ± 6 m·min⁻¹; CW simulations: 38 ± 5 b·min⁻¹; OD matches: 54 ± 45 m·min⁻¹) were associated with CW simulation training compared to TCT. Irrespective of playing position, technical demand was greatest during TCT compared to matches or CW simulations. Collectively, this evidence suggests that neither training modality consistently provided players with a training stimulus that replicated a match. Importantly, the use of CW simulations may be limited in the transfer of match-specific skills and tactical strategies due to the lower physical and physiological intensities when compared to match-play.

Given the findings of Study 2, Study 3 examined the movement demands and physiological responses of BZ, and determined its inter-session reproducibility. Unlike CW simulations whereby players trained using the entire space of a cricket field, BZ enclosed players within the inner circle of a typical cricket field using netting. Thirteen male, amateur cricket players (age: 22.8 ± 3.5 yr, height: 1.78 ± 0.06 m, body mass: 78.6 ± 7.1 kg) completed two separate BZ sessions during which HR, movement patterns, blood lactate concentration ([BLa⁻]) and RPE were recorded. During a BZ session, batsmen reported the greatest physical demand (mean speed: 63 ± 9 m·min⁻¹), followed by medium-fast bowlers (60 ± 10 m·min⁻¹). Regardless of playing position, the majority of time (79-90%) was spent between 51-85% of maximum heart rate (HR_max) and [BLa⁻] between 1.1-2.0 mmol·L⁻¹. Ratings of perceived exertion ranged between 4.2-6.0. The movement demands and physiological responses of players, did not differ between sessions (p > 0.05), irrespective of playing position. Mean speed (CV: 7-9%; Intra-class correlation [ICC]: 0.56-1.00) and peak %HR_max achieved
(CV: 6-8%; ICC: -0.80-0.73) demonstrated acceptable reliability across each playing position. Thus, the use of BZ as a training method may be suitable for replicating match demands. Furthermore, the results also suggest that the training stimulus provided through BZ is consistent.

Study 4 compared the physiological, physical and technical demands of cricket players between BZ, TCT and OD matches. Eleven amateur, male cricket players (age: 22.2 ± 3.3 yr, height: 1.82 ± 0.06 m, body mass: 80.4 ± 9.8 kg) completed four BZ and four TCT sessions whilst measures of HR, [BLa], RPE and movement patterns of players were collected. The involvements of technical skill of each player were quantified by post hoc video analysis. Following this, similar measures were collected from 42 amateur, male cricket players (23.5 ± 4.7 yr, 1.81 ± 0.07 m, 81.4 ± 11.4 kg) during ten OD matches. Batsmen performed with the greatest HR$_{\text{mean}}$ (164 ± 12 b·min$^{-1}$) during BZ, likely due to the greater relative distance covered at a high-intensity (HI) (21 ± 7 m·min$^{-1}$). The greatest technical demand (number of [#] balls faced: 6 ± 1 balls·min$^{-1}$, # balls hit: 4 ± 1 balls·min$^{-1}$, % good contact shots: 82 ± 7%) for batsmen was observed during TCT. Similarly within other playing positions, a greater HR$_{\text{mean}}$ was reported during BZ in comparison to TCT and OD matches regardless of playing position. Therefore, across each of the different playing positions the physiological, physical and technical demands of BZ and TCT replicate or exceed the relative demands of a OD match in amateur players.

Finally, Study 5 examined the influence of modifying the constraints associated with the BZ training environment. Eleven male, cricket players (22.2 ± 3.6 yr;
1.80 ± 0.06 m; 81.7 ± 11.4 kg) performed four modified scenarios of BZ which included a reduction in field size, the removal of a fielder, a combination of these two modifications and the inclusion of new playing rules. As with previous studies, each player’s HR, [BLa], RPE and movement patterns were measured during each BZ scenario. Between the different scenarios, the greatest HR response and [BLa] resulted from the changes in playing rules, which resulted from the increased movement demands (mean speed, HI activity) of this scenario ($p < 0.05$), most notably for batsmen ($HR_{\text{mean}} : 158 \pm 17 \text{ b} \cdot \text{min}^{-1}$, mean speed: $67 \pm 7 \text{ m} \cdot \text{min}^{-1}$) and wicketkeepers ($HR_{\text{mean}} : 145 \pm 9 \text{ b} \cdot \text{min}^{-1}$, mean speed: $37 \pm 10 \text{ m} \cdot \text{min}^{-1}$). By comparison, manipulating the size of the BZ playing field or the number of fielders present did not appear to significantly influence ($p > 0.05$) the physical demands or physiological responses of players. As such, the manipulation of BZ constraints can help to provide a range of match-specific training environments.

Collectively, these findings demonstrate the advantages of using BZ as a cricket training format as opposed to game-based CW simulations. Overall, the physiological, physical and technical demands of BZ appear similar to or exceed that of a OD match as well as the more traditional forms of cricket training. This demonstrates that BZ can provide a sufficient match-appropriate training load (TL). Importantly, BZ demonstrated an acceptable level of reliability between training sessions, suggesting that a consistent TL can be applied. Furthermore, manipulating BZ constraints can vary the training response to provide variation to help develop different aspects of a cricket player’s game, such as technical skill or conditioning status.
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List of Abbreviations and Nomenclature

\( p \)  
- Alpha

ANOVA  
- Analysis of variance

AU  
- Arbitrary unit

balls min\(^{-1} \)  
- Balls per minute

BATEX  
- Batting exercise

b min\(^{-1} \)  
- Beats per minute

\([BLa]\)  
- Blood lactate concentration

BZ  
- Battlezone

cm  
- Centimetre

COD  
- Changes of direction

CR-10  
- Category ratio 10 scale

r  
- Coefficient of correlation

CV  
- Coefficient of variation

CW  
- Centre-wicket

\( ^\circ \)  
- Degree

\( ^\circ C \)  
- Degrees Celsius

d  
- Cohen’s effect size

FBTS  
- Field-based team sports

GPS  
- Global positioning system

>  
- Greater than

HDOP  
- Horizontal dilution of position

HR  
- Heart rate

HR\(_{\text{max}}\)  
- Maximum heart rate

\( \%HR_{\text{max}} \)  
- Mean heart rate as a percentage of maximum heart rate

HR\(_{\text{mean}}\)  
- Mean heart rate

HI  
- High-intensity

Hz  
- Hertz

ICC  
- Intra-class correlation
kg  Kilogram/s
km  Kilometre/s
km h\(^{-1}\) Kilometres per hour
<  Less than
L min\(^{-1}\) Litres per minute
LI  Low-intensity
m  Metre/s
m h\(^{-1}\) Metres per hour
m min\(^{-1}\) Metres per minute
m s\(^{-1}\) Meters per second
μL  Microlitre
ml kg\(^{-1}\) min\(^{-1}\) Millilitres per kilogram per minute
mmol L\(^{-1}\) Millimole per litre
min  Minute
n  Number
#  Number of
OD  One-Day
%  Percent
h\(^{-1}\) Per hour
RPE  Rating of perceived exertion
s  Second/s
SD  Standard deviation of the mean
SSG  Small-sided games
TCT  Traditional cricket training
TL  Training Load
T20  Twenty20
TE\%  Typical error as a percentage of the mean
\(\dot{V}_O_2\)  Oxygen consumption
\(\dot{V}_O_2\)\(_{max}\)  Maximal aerobic capacity
yd  Yard
yr  Year/s
List of Publications Arising from this Thesis

Peer Reviewed Articles


**Conference Proceedings**


Chapter 1

*Introduction*
Background Information

Cricket continues to undergo a dramatic increase in the level of professionalism related to athlete preparation for training and competition. This has placed an increased emphasis on sports science practices that maximise the integrated physical and skill development of cricket players. Importantly, this has resulted in an increased amount of research that has focused on cricket, although a large portion has solely reported on the biomechanics (Elliot, Foster & Gray, 1986; Elliott, Wallis, Sakurai, Lloyd & Besier, 2002; Hurrion, Dyson & Hale, 2000; Ranson, Burnett, King, Patel & O'Sullivan, 2008) or injury surveillance (Dennis, Farhart, Goumas & Orchard, 2003; Elliot, 2000; Mansingh, Harper, Headley, King-Mowatt & Mansingh, 2006; Orchard, James & Portus, 2006; Saw, Dennis, Bentley & Farhart, 2009) of players. More recently, the physiological responses and physical demands of elite cricket match-play has received an increasing level of attention (Christie, Todd & King, 2008; Duffield, Carney & Karppinen, 2009; Nicholson, Cooke, O'Hara & Schonfeld, 2009; Petersen, Pyne, Dawson, Portus & Kellett, 2010). This increase in cricket research has coincided with an expansion of the international cricketing schedule, which now includes new match formats and an increase in the number of matches played each year.

Importantly, it is likely that this expansion of cricket and the introduction of new match formats has driven the increased demand of short- and long-term athlete development. Until halfway through the 20th century, only multi-day cricket (3-5 days play) was played throughout in the world. However in more recent times, cricket has evolved toward shorter and faster match formats, referred to as
limited overs cricket (OD and Twenty20 [T20]), which allows a result to occur in one day. These limited overs cricket matches are typically characterised by higher match intensities, for example, as players are likely to attempt more quick singles in order to score a greater number of runs within a shorter time period (Petersen et al., 2010). Due to the rigours of the current cricket schedule, elite players regularly travel either interstate or internationally, and are expected to perform at a high standard with limited training and acclimation time. Therefore, effective and time-efficient training programs need to be employed to ensure a specific training response is provided by each session. Despite the increased research focus on understanding demands of contemporary cricket match formats, the typical training methods adopted by cricket coaches have not similarly progressed, and may not reflect the current physiological and physical demands of cricket players (Petersen et al., 2010; Pyke & Davis, 2010).

Traditionally, the majority of cricket training practices have involved separate conditioning and skills training sessions (Pyke & Davis, 2010), which despite allowing players to develop their physical fitness and technical abilities, fails to provide players with a match-specific training environment. To overcome this issue, the use of game-based training or CW simulations have been introduced to allow players to train on a typical sized cricket field under match conditions (Pyke & Davis, 2010). Unfortunately, no information currently exists which examines the demands associated with this game-based training in cricket and as such, it remain unknown if this training format replicates a match environment. Given the increased level of professionalism of cricket, it is
important for coaches to design training programs to provide players with cricket-specific physiological, physical and technical TL’s.

Research within other sports has identified the benefits of using SSG as an alternative to more traditional training methods and game-based training for improving an athlete’s level of physical conditioning and technical ability (Dellal et al., 2008; Gabbett, 2006; Hill-Haas, Coutts, Rowsell & Dawson, 2009a; Sassi, Reilly & Impellizzeri, 2004). It is suggested that a distinct advantage of SSG is that it provides players with an environment that replicates competitive match demands, thus eliciting the concurrent development of technical skills, decision-making and match awareness whilst providing a sufficient conditioning response. Over the past decade, SSG have been successfully implemented into the training schedules of numerous field-based team sports (FBTS), such as soccer and rugby league (Davids, Araújo, Correia & Vilar, 2013; Gabbett, Jenkins & Abernethy, 2009). Accordingly, it is possible that similar beneficial training responses may be observed with cricket-specific SSG. Currently the use of SSG within cricket is limited, with coaches preferring the use of more traditional training methods and game-based CW practice as opposed to SSG which may not allow for match-specific demands and skills to be transferred into match-play.

**Statement of Problem**

Previous research has demonstrated that game-based training helps to provide a suitable alternative to more traditional forms of conditioning training across a range of FBTS (Gabbett et al., 2009). However, the research detailing game-
based training, in particular SSG, has focused on sports typically more heavily reliant upon physical conditioning and development, and to a lesser degree skill proficiency (e.g. soccer and rugby league). To date, no research has detailed the use of game-based training in sports that are heavily dependent on technical and tactical skills, such as cricket. Typically cricket training involves net-based sessions or game-based CW practice, which are more tailored towards the development of a player’s technical ability, separate to their physical fitness level (Pyke & Davis, 2010). Little information exists detailing the demands of traditionally used cricket training methods, with Petersen, Pyne, Dawson, Kellet and Portus (2011a) suggesting that simulation and skill-based drills fail to replicate cricket match demands. The recent development of a cricket-specific SSG termed ‘Battlezone’ (Renshaw, Chappell, Fitzgerald, Davison & McFadyen, 2010) has provided an opportunity for the game-based training approach to be implemented in cricket. Importantly similar to previous research (Gabbett, Abernethy & Jenkins, 2012a; Hill-Haas, Coutts, Dawson & Rowsell, 2010; Hill-Haas et al., 2009a), the implementation of BZ can be constrained by factors such as field size, player numbers and playing rules. Therefore, it is likely that the manipulation of these variables may alter the imposed physiological, physical and technical responses of training. In their development of BZ, Renshaw et al. (2010) stated that it provided a realistic practice environment that enabled the transfer of skills learnt during training into match-play. As such, this may enable players to develop their capacity to solve cricket-specific problems or to execute skills more proficiently during periods of physiological fatigue. However, these authors reported primarily on the skill transfer properties of BZ and did not discuss any associated physical and
physiological demands. As such, it remains to be determined whether BZ provides players with a match-intensive environment that replicates the physiological and physical demands of cricket whilst concurrently allowing a sufficient stimulus to improve technical capacity. To date, no research has examined the physical and physiological intensities of cricket players during BZ training. Furthermore, no research has reported on the internal and external TL’s typical of cricket-specific SSG when compared to more TCT methods such as net sessions and fielding drills and match data.

**Purpose of the Thesis**

The primary aim of this series of research studies was to report on the efficacy of existing cricket training practices and to determine if game-based training, such as BZ, was effective in creating the physical and technical demands of a match environment. Specifically, this research thesis aimed:

1. To review the existing literature that details the physical demands and physiological loads experienced by cricket players during both training and match-play;

2. To determine the accuracy and reliability of 5, 10 and 15 Hz GPS devices in quantifying the movement patterns of cricket-specific activities (Study 1);

3. To compare the physical, physiological and technical responses of elite (Study 2) and amateur (Study 4) cricket players during game-based training, TCT methods and competitive matches;
4. To quantify the physiological responses, movement patterns and technical characteristics of cricket players whilst participating in a generic BZ session (Study 3);

5. To determine the between-training session reproducibility of generic BZ sessions (Study 3), and;

6. To examine the effect of rule modifications and playing environment on the physical and physiological responses of cricket players during BZ sessions (Study 5).

Significance of the Research

The research bears great significance for the strength and conditioning practices used within cricket, given the lack of available data and slow development of training practices. It is anticipated the research outcomes will provide information on the TL’s associated with various methods of cricket training such as net-based training and CW practice. In turn, these data can contribute to the preparation of match-specific conditioning and skills training programs for both elite and amateur cricket players. In addition to this, the use of BZ in cricket is a novel concept and the physiological responses, as well as the physical and technical demands associated with BZ training are not yet understood. Therefore, comprehensive research is required to quantify the demands of BZ training and determine whether it presents an effective training method for cricket players. It is envisioned that the outcomes of this research will provide cricket coaches and conditioning staff with data relating to the internal and external TL’s experienced by cricket players during BZ training.
Overall, the aim of this thesis is to determine if game-based training such as CW simulations and/or BZ provide cricket players with a relevant training stimulus and are representative of match-specific loads.

**Limitations and Assumptions**

The following limitations and assumptions may apply to the present study:

1. *Specificity of the results*
   
The data collected during this study were obtained from well-trained, young cricket players, with a minimum of ten years playing experience. The results may lack validity for players with less playing experience or within age groups dissimilar to those used in the current studies.

2. *Maintenance of physiological capacities and technical abilities*
   
In some instances throughout the present study, the physiological, physical and skills-based measures were collected over numerous weeks for all participants. It is therefore assumed that participants maintained their physiological capacities and technical abilities throughout the entirety of the data collection period.

3. *Environmental conditions*
   
The preparation of the cricket pitch and field was subject to changes in atmospheric conditions as matches and training sessions were played outdoors. The quality of the playing environment was limited by the preparation time, which may have varied throughout the testing periods. However, the playing environment was standardised as best as possible.
4. **Technology restrictions**

The use of GPS technology to monitor physical demands is limited by its varying reliability and validity, particularly when performing high-speed movements such as those typical of team sports (Aughey, 2011).

5. **Variability of cricket**

Given the nature of the sport, individual cricket players have varying levels of proficiency in the technical skills required for cricket match-play. For example, batsmen may be stronger at playing off-side shots or have specific shots they favour. Alternatively, bowlers differ considerably in the length of their run-ups and their preferred line and length of the balls they bowl. These individual differences may influence the physiological responses and movement characteristics of the other players during the testing periods.

**Delimitations**

The following delimitations may apply to the present research:

1. **Limited sample size**

Due to the time-demanding nature of the studies conducted throughout this research project, the number of well-trained cricket players were recruited for each individual study was limited. However, the sample size of each individual study is typical of previous research reporting on the physiological responses and physical demands of team-sport athletes during SSG (Hill-Haas, Dawson, Coutts & Rowsell, 2009b).
2. *Gender restrictions of the participants*

The participants recruited across the research project were restricted to males to avoid any effect of gender on performance.

3. *Sport restriction of the participants*

The participants recruited for the present research project were restricted to cricket players currently participating in a competitive cricket season. The results of the present study may therefore not apply to other team sports, other than those who are competitive within similar sports or activities.

4. *Sample representation*

The data contained within the entire research project are based on a specific sample of participants, and therefore may not be a true representation of similar populations.
Chapter 2

Review of the Literature
Introduction

The purpose of this review is to summarise past research that has examined the sport of cricket, as well as game-based and SSG training. Initially, the review provides a brief description of the origins, definitions and rules of cricket. The next section addresses research that has focused on cricket and is divided into two sections:

1. Physical demands of players during match-play and training;
2. Physiological demands of players during match-play and training.

Following this, the review then provides a brief description of the use of game-based training. Information is provided on SSG and is separated into four sections:

1. Variables that influence the intensity and demands of SSG;
2. Variables that influence the technical skills of SSG;
3. The reliability and reproducibility of SSG;
4. Comparison of the demands and intensity levels between SSG and other training methods; and,

The final section of the review describes the nexus between SSG and cricket, before providing a summary and conclusion for the review.

Description of Cricket

Currently, cricket is played at both the junior and senior levels by males and females according to the Laws of Cricket (Marylebone Cricket Club, 2010), throughout more than 100 nations including South Africa, England, Australia,
Pakistan, India, Sri Lanka, West Indies, New Zealand and Bangladesh. At present, there are three different formats (multi-day, OD and T20 cricket) of the game that exist at the professional level. Regardless of the format, the objective of cricket is to score a greater number of runs than the opposing team (Marylebone Cricket Club, 2010). During cricket match-play, one team is required to score runs whilst the opposing team bowls and fields, trying to dismiss the batsmen and restrict the number of runs scored. A run is scored when the striking batsman hits the ball with his bat and runs to the opposite end of the pitch where they touch the crease without being dismissed. Once all batsmen have been dismissed or the maximum number of allotted overs have been bowled, the teams switch between batting and bowling (Marylebone Cricket Club, 2010).

A typical cricket team consists of 11 players (Marylebone Cricket Club, 2010), with each having a specific role depending on their primary skill. For example, a specialist batsman is required to attempt to score the majority of the runs for the team. Alternatively, bowlers are required to propel the ball towards the opposing teams batsmen using an action in which elbow extension is minimised to prevent a throw occurring (Marylebone Cricket Club, 2010). It is the responsibility of the bowlers to both dismiss the batsmen on the opposing team and restrict the amount of runs scored by these players. Bowlers can be classified according to the type of delivery they typically complete. Fast- and medium-paced bowlers are those who can bowl the ball at speeds ranging between >140km h\(^{-1}\) and 120-140 km h\(^{-1}\), respectively. Fast- and medium-paced bowlers use factors such as swing or seam movement to take wickets and
restrict runs. A spin bowler bowls at a slower speed (~80-90 km h\(^{-1}\)) and places rotation on the ball prior to ball release, so that it will deviate off the pitch making the ball more difficult to hit. Spin bowlers are referred to as either leg- or off-spin bowlers depending on the direction of the spinning ball. Separately, the wicketkeeper is a player who is situated behind the stumps on the team who is currently bowling. This player’s primary role is to catch balls that are delivered by the bowler and are not hit by the batsmen. All other players on the bowling side are referred to as fielders and are required to stop the ball hit by batsmen to restrict the runs scored.

Whilst cricket is one of the world’s oldest and most popular organised sports, there is a lack of scientific research detailing training methods and match intensities. However, the body of knowledge that details the physical and physiological responses of cricket has grown in recent times (Bartlett, 2003; Noakes & Durandt, 2000). Recently, literature has demonstrated that the physiological and physical demands of cricket varies across the different positions and game formats (Christie et al., 2008; Duffield et al., 2009; Petersen et al., 2010; Petersen, Pyne, Portus & Dawson, 2009b). Based on this information, tailored conditioning programs that are specific to each player’s role and type of match demands can be developed and prescribed. Historically, it has been common for cricket training sessions to be separated into isolated conditioning (interval and intermittent running) and skills (net-based batting and bowling, fielding drills) sessions (Pyke & Davis, 2010). Currently, the training demands placed upon cricket players during more traditional training methods is not well understood and as such may limit their effectiveness in replicating
match demands. In addition to this, the use of separate training sessions may limit the concurrent improvements of both physical fitness and technique across a period of training.

**Physical Demands of Cricket Players**

Contemporary research reporting on the physical demands of cricket players refutes the suggestion that cricket is a low-intensity (LI) activity, demonstrating that cricket is played at a considerably high physical intensity, especially given the extended duration of matches (Petersen et al., 2009b). The recent introduction of GPS technology has increased the capacity to quantify the physical demands of cricket match-play and training. More specifically the introduction of technology such as GPS devices has led to recent reporting on the differences in match intensities between multi-day, OD and T20 cricket within each specific cricket playing position (Petersen et al., 2010).

**Match Demands of Medium-Fast Bowlers**

Petersen and colleagues (Petersen et al., 2010; Petersen et al., 2009b; Petersen, Pyne, Portus, Karppinen & Dawson, 2009c; Petersen, Pyne, Portus & Dawson, 2011b) have reported on the movement patterns of cricket players using GPS technology. Combined with McNamara, Gabbett, Naughton, Fahart and Chapman (2013), these studies collectively revealed that medium-fast bowlers are required to perform at the highest intensity of all cricket positions. These data demonstrated that a medium-fast bowling innings is typically characterised by a large percentage of LI activity (76-86%; Table 2.1, over the page), interspersed with repeated bouts of HI activity incurred during the
bowlers run-up. Importantly, the data demonstrates that the shorter the game format (T20 < OD < multi-day), the greater relative physical intensity that is maintained, as quantified by the distance covered per hour. This greater intensity of the shorter game formats is also characterised by the quicker recovery time between each HI effort. Further, Petersen et al. (2010) demonstrated that the overall physical demand (load) of a medium-fast bowler increases with the length of the game format. For example, during a typical multi-day match, a medium-fast bowler covers between 23-24 km (Petersen et al., 2010; Petersen et al., 2011b), whereas during an OD and T20 match, they cover between 13-15 km (Petersen et al., 2010; Petersen et al., 2009c; Petersen et al., 2011b) and 6-9 km (Petersen et al., 2009b; Petersen et al., 2011b), respectively.

**Table 2.1:** Physical demands of elite, medium-fast bowlers during match-play (mean ± standard deviation [SD]).

<table>
<thead>
<tr>
<th>Study</th>
<th>Match Format</th>
<th>Total Distance (m·h⁻¹)</th>
<th>Total LI Distance (m·h⁻¹)</th>
<th>Total HI Distance (m·h⁻¹)</th>
<th>Mean Speed (m·min⁻¹)</th>
<th>Recovery Ratio (1:x)</th>
<th>HI Efforts (#h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petersen et al. (2009b)</td>
<td>T20</td>
<td>6367 ± 1120</td>
<td>4862 ± 1131</td>
<td>1505 ± 506</td>
<td>106 ± 19</td>
<td>32 ± 10</td>
<td>122 ± 33</td>
</tr>
<tr>
<td>Petersen et al. (2009c)</td>
<td>OD</td>
<td>4544 ± 729</td>
<td>3441 ± 24</td>
<td>150 ± 25</td>
<td>76 ± 12</td>
<td>68 ± 12</td>
<td>55 ± 9</td>
</tr>
<tr>
<td>Petersen et al. (2010)</td>
<td>T20</td>
<td>4171 ± 971</td>
<td>3352 ± 455</td>
<td>819 ± 427</td>
<td>70 ± 17</td>
<td>25 ± 18</td>
<td>61 ± 25</td>
</tr>
<tr>
<td>Petersen et al. (2010)</td>
<td>OD</td>
<td>3831 ± 839</td>
<td>3183 ± 579</td>
<td>693 ± 260</td>
<td>64 ± 14</td>
<td>25 ± 7</td>
<td>54 ± 14</td>
</tr>
<tr>
<td>Petersen et al. (2010)</td>
<td>Multi-Day</td>
<td>3774 ± 802</td>
<td>3126 ± 341</td>
<td>648 ± 371</td>
<td>63 ± 13</td>
<td>38 ± 31</td>
<td>56 ± 29</td>
</tr>
<tr>
<td>Petersen et al. (2011b)</td>
<td>OD</td>
<td>4279 ± 677</td>
<td>3584 ± 759</td>
<td>694 ± 168</td>
<td>71 ± 11</td>
<td>73 ± 21</td>
<td>52 ± 11</td>
</tr>
</tbody>
</table>
Training Demands of Medium-Fast Bowlers

At the current point in time, little research is available reporting on the physical demands of medium-fast bowlers during any form of structured cricket training. Similar to previous match data (Petersen et al., 2010), McNamara et al. (2013) reported greater physical demands were placed upon medium-fast bowlers in comparison to other playing position during physical preparation prior to competition. However, it is unclear what this physical preparation involved. Although limited, a small number of studies have reported the physical demands of medium-fast bowlers during simulated bowling protocols. Initially, Duffield et al. (2009) reported that a total of 6546 ± 885 m was covered during two 6-over spells, with 77% of this distance covered at a LI (<14 km·h⁻¹). This percentage of LI activity performed during a match-simulated bowling protocol is similar to that of an actual cricket match (Table 2.1), despite the slightly different definition of LI activity. During the studies of Minnett, Duffield, Kellet and Portus (2012b) and Minnett, Duffield, Kellet and Portus (2012a), medium-fast bowlers completed 4328 ± 707 m and 8676 ± 1295 m during a single 6- and 10-over bowling spell, respectively. In comparison to Duffield et al. (2009) and typical match data (Petersen et al., 2010), a considerably smaller percentage of distance was covered at LI (<7 km·h⁻¹) (59-61%) in the studies of Minnett et al. (2012a; 2012b). However, the different classification of LI activity is most likely the cause of this variance. From this information it is apparent that the physical demands of medium-fast bowlers during simulated bowling protocols are highly variable and is likely to differ between each individual bowler due to their differing bowling actions and run ups. In addition to this, none of these studies involved the use of a batsman for the medium-fast bowlers to bowl at during the
protocols and were interspersed with designated movements between balls in order to replicate a match environment. This may not fully replicate the sporadic nature of cricket and as such not provide physical demands truly replicable of a cricket match. Therefore, research into the physical demands of medium-fast bowlers whilst performing net-based or other training formats must be completed to allow coaches to develop effective and specific medium-fast bowling training programs.

**Match Demands of Batsmen**

The reported distances covered by elite cricket batsmen during competitive match-play ranges between 4-13 km (Petersen et al., 2010) (Table 2.2, see over the page). However, these data assume that the batsmen batted for the entire innings across each playing format. As highlighted in Petersen et al. (2010), the workload of batsmen is highly variable between matches, as it is dependent on the length of time a batsman spends at the crease, which in turn, is reflective of skill proficiency and environmental contexts. It is possible that the playing level of batsmen may influence the total distance covered, with state-level batsmen covering a greater distance during an 80 min T20 innings than academy-level batsmen (Petersen et al., 2010; Petersen et al., 2009b). Such variation may suggest that a lower percentage of runs were scored from boundaries during the matches involving state-level players, which required less running between the wickets, and subsequently less distance to be covered.
Table 2.2: Physical demands of elite batsmen during match-play (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Match Format</th>
<th>Total Distance (m h⁻¹)</th>
<th>Total LI Distance (m h⁻¹)</th>
<th>Total HI Distance (m h⁻¹)</th>
<th>Mean Speed (m min⁻¹)</th>
<th>Recovery Ratio (1:x)</th>
<th>HI Efforts (# h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petersen et al. (2009b)</td>
<td>T20</td>
<td>4866 ± 900</td>
<td>4078 ± 1242</td>
<td>788 ± 416</td>
<td>81 ± 8</td>
<td>76 ± 34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T20</td>
<td>2429 ± 657</td>
<td>1970 ± 455</td>
<td>458 ± 202</td>
<td>40 ± 11</td>
<td>38 ± 13</td>
<td>28 ± 6</td>
</tr>
<tr>
<td>Petersen et al. (2010)</td>
<td>OD</td>
<td>2476 ± 720</td>
<td>2087 ± 519</td>
<td>389 ± 201</td>
<td>41 ± 12</td>
<td>50 ± 21</td>
<td>39 ± 16</td>
</tr>
<tr>
<td></td>
<td>Multi-Day</td>
<td>2064 ± 607</td>
<td>1804 ± 528</td>
<td>260 ± 79</td>
<td>34 ± 10</td>
<td>61 ± 10</td>
<td>28 ± 6</td>
</tr>
</tbody>
</table>

Comparing across the different match formats, batsmen perform at the highest intensity during limited overs cricket match-play when compared to multi-day cricket (Petersen et al., 2010). The majority of a batsman’s innings is spent performing LI activities that are interspersed with HI activities that are more frequent during one day match-play (Petersen et al., 2010). This increased intensity of batsmen during limited overs cricket is further reflected by a faster mean speed and shorter work-to-recovery ratio. Using video analysis, Duffield and Drinkwater (2008) reported similar work-to-recovery (HI-to-LI activity) ratios for batsmen that scored 100 runs or more within an innings, in both OD (1:47 s) and multi-day (1:67 s) match formats. It is possible that the work rate of batsmen may be highly dependent on several factors including the length of the batting innings, the bowling quality and the type of bowlers faced. This may explain the reported variation in the number of HI efforts performed during the different match formats. Regardless of the format however, the evidence suggests that successful batting for extended periods requires a consistently high work rate.
Training Demands of Batsmen

Information regarding the physical demands of batsmen whilst training or involved in game simulations is sparse. Recently, an intermittent batting exercise (BATEX) protocol was designed to simulate a typical OD international century (Houghton, Dawson & Rubenson, 2011a; Houghton, Dawson, Rubenson & Tobin, 2011b). During the protocol, batsmen faced a total of 180 deliveries interspersed with a series of shuttle runs that were completed across the length of a cricket pitch. When compared to the relative distance covered during a typical OD batting innings (2476 ± 720 m·h⁻¹), the BATEX protocol (2171 ± 157 m·h⁻¹) was performed at a slightly lower overall intensity, despite a greater proportion of time spent at HI (OD: 389 ± 201 m·h⁻¹; BATEX: 577 ± 99 m·h⁻¹). This difference was attributed to the lower amount of LI activity during BATEX as opposed to a OD match (Houghton et al., 2011b). Further to this, the BATEX protocol resulted in less recovery time between HI efforts (1:31 s) than a typical OD batting innings (1:50 s). From this, Houghton et al. (2011b) suggested that the increased HI running demands of the BATEX protocol would benefit players as they would be provided with higher than normal physical demands. Similar to medium-fast bowlers, there is little research that details the physical demands of batsmen whilst performing typical net-based batting sessions. Again, more information is needed to effectively tailor training sessions to ensure that effective batting sessions which replicate match-play are developed.
**Match Demands of Other Playing Positions**

Historically, the majority of cricket research has focused on medium-fast bowlers and batsmen with little emphasis placed on the other playing positions. As such, any available information detailing the physical demands of spin bowlers, fielders and wicketkeepers is somewhat lacking. In an original investigation, Petersen et al. (2009b) reported on the physical demands of all playing positions during a number of T20 matches, and reported that the intensity was higher than that reported for a OD match. For example, Table 2.3 (see page 23) displays the total hourly distance of elite spin bowlers ranges between 3166-3486 m h⁻¹ and 3292-6403 m h⁻¹ during OD and T20 matches, respectively. The percentage of this distance covered at a HI ranged between 9-14% and 7-9% for the OD and T20 matches, respectively. Further to this, the mean running speed of spin bowlers during OD matches was between 53-61 m min⁻¹, whereas during T20 matches it ranged from 55-107 m min⁻¹. However, the current information regarding the physical demands of spin bowlers may be misleading due to the paucity of available research. Therefore, for valid training sessions to be developed and based on match data, more information on the demands of these bowlers must become available. Although, it is apparent that spin bowlers perform at a significantly lower intensity than medium-fast bowlers and batsmen during competitive match-play.

Separately, fielders cover a total relative distance of anywhere between 2476-6106 m h⁻¹, which is likely to reflect the great variation in the placement of different fielding positions (Table 2.3). This large variation reflects the differences between the physical intensity of fielding between match formats.
Rudkin and O'Donoghue (2008) reported a similar total hourly distance for a cover-point fielder (~2500 m h⁻¹) during a multi-day match, with a large proportion of the match spent performing LI activities. These researchers reported that a cover-point fielder in a first-class cricket match spent approximately 99% of the total fielding session either standing stationary, walking, shuffling or jogging. Not surprisingly, this demonstrates a direct negative relationship between the intensity of fielding and the number of overs in a match.
Table 2.3: Physical demands of elite spin bowlers, fielders and wicketkeepers (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Match Format</th>
<th>Playing Position</th>
<th>Total Distance (m h⁻¹)</th>
<th>Total LI Distance (m h⁻¹)</th>
<th>Total HI Distance (m h⁻¹)</th>
<th>Mean Speed (m min⁻¹)</th>
<th>Recovery Ratio (1:x)</th>
<th>HI Efforts (#h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petersen et al. (2009b)</td>
<td>T20</td>
<td>Spin Bowler</td>
<td>6403 ± 1176</td>
<td>4753 ± 1111</td>
<td>457 ± 504</td>
<td>107 ± 20</td>
<td>42 ± 26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fielder</td>
<td>6106 ± 981</td>
<td>4917 ± 1087</td>
<td>1289 ± 737</td>
<td>102 ± 16</td>
<td>98 ± 43</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wicketkeeper</td>
<td>4825 ± 570</td>
<td>4478 ± 525</td>
<td>462 ± 99</td>
<td>80 ± 10</td>
<td>38 ± 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T20</td>
<td>Spin Bowler</td>
<td>3292 ± 640</td>
<td>2995 ± 492</td>
<td>297 ± 148</td>
<td>55 ± 11</td>
<td>63 ± 36</td>
<td>5 ± 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fielder</td>
<td>3217 ± 930</td>
<td>2979 ± 667</td>
<td>468 ± 263</td>
<td>54 ± 16</td>
<td>43 ± 28</td>
<td>8 ± 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wicketkeeper</td>
<td>2493 ± 495</td>
<td>2139 ± 305</td>
<td>344 ± 190</td>
<td>42 ± 8</td>
<td>51 ± 21</td>
<td>5 ± 2</td>
</tr>
<tr>
<td>Petersen et al. (2010)</td>
<td>OD</td>
<td>Spin-Bowler</td>
<td>3166 ± 536</td>
<td>2872 ± 393</td>
<td>294 ± 143</td>
<td>53 ± 9</td>
<td>54 ± 16</td>
<td>4 ± 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fielder</td>
<td>3081 ± 723</td>
<td>2757 ± 567</td>
<td>324 ± 156</td>
<td>51 ± 12</td>
<td>62 ± 41</td>
<td>5 ± 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wicketkeeper</td>
<td>2711 ± 366</td>
<td>2471 ± 300</td>
<td>240 ± 66</td>
<td>45 ± 6</td>
<td>64 ± 18</td>
<td>2 ± 1</td>
</tr>
<tr>
<td></td>
<td>Multi-Day</td>
<td>Fielder</td>
<td>2476 ± 630</td>
<td>2253 ± 488</td>
<td>223 ± 131</td>
<td>41 ± 11</td>
<td>90 ± 52</td>
<td>3 ± 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wicketkeeper</td>
<td>2767 ± 437</td>
<td>2658 ± 365</td>
<td>109 ± 72</td>
<td>46 ± 7</td>
<td>167 ± 73</td>
<td>2 ± 4</td>
</tr>
<tr>
<td>Petersen et al. (2011b)</td>
<td>OD</td>
<td>Fielder</td>
<td>3430 ± 883</td>
<td>3035 ± 980</td>
<td>396 ± 224</td>
<td>57 ± 15</td>
<td>134 ± 73</td>
<td>34 ± 17</td>
</tr>
<tr>
<td></td>
<td>Multi-Day</td>
<td>Fielder</td>
<td>3342 ± 759</td>
<td>2892 ± 764</td>
<td>458 ± 177</td>
<td>56 ± 13</td>
<td>116 ± 37</td>
<td>34 ± 11</td>
</tr>
</tbody>
</table>
Lastly, wicketkeepers have been shown to perform at the lowest physical intensity of all playing positions during a match. In particular, only 4% of the total hourly distance is completed through HI activities during a multi-day match (Petersen et al., 2010). This finding reflects the demands of the wicketkeepers role, as a high proportion of time is spent squatting, rising and side-stepping whilst trying to catch the ball. As a result, the frequent explosive and HI activities performed by wicketkeepers are not likely to be detected by GPS technology. Therefore, this role explains the lower physical running demands reported for wicketkeepers during a typical cricket match.

**Training Demands of Other Playing Positions**

In a recent study, Petersen et al. (2011a) examined the demands of various cricket training activities (n = 28) that could be separated as either game simulation, skill session or conditioning session (HI: >7 mmol·L⁻¹; LI: <7 mmol·L⁻¹) across a 14 week off-season. During the conditioning sessions, players covered approximately 7 km, with 40-63% of this distance completed during LI activities (walking and jogging). These conditioning sessions were characterised by a high number of HI efforts (133 ± 69), that were typically interspersed with small recovery periods (1:4 s). As reported previously, Petersen et al. (2011a) demonstrated that the physical demands of these conditioning sessions were actually greater than during all three international cricket formats. Specifically, the hourly distance covered during the game simulation (~3 km·h⁻¹) and skill sessions (~3 km·h⁻¹) was similar to the earlier work of Petersen et al. (2010). Due to the large variance in the movement
patterns and skills performed by spin bowlers, fielders and wicketkeepers, it is expected that the physical load experienced during match-play is likely to differ.

**Summary of the Physical Demands of Cricket**

Collectively, the current research shows that the majority of cricket during both match-play and training is performed at LI (stationary, walking and jogging). As a result, the amount of HI activity performed during either a cricket match or training is limited due to the intermittent nature of the movement demands associated with cricket. However, the percentage of LI and HI activity performed is specific to each individual playing position and the training format being undertaken. For example, while batsmen tend to cover a greater overall relative distance during a batting innings, a greater percentage of time was spent completing HI activity during a simulated batting innings (Houghton et al., 2011b). By comparison, medium-fast bowlers covered considerably more distance during all match and training formats than any other playing position. Furthermore, as shown by Petersen et al. (2011a) the conditioning drills performed by elite cricket players evoke a considerably greater physical demand than that typical of a OD match. Based on this evidence, the physical demands placed on these players during training must cater to the specific needs of each playing position to ensure that a sufficient, match-specific conditioning response is gained. However for the training responses to be completely match-specific, the physiological responses associated with these physical demands must also be understood.
Physiological Responses of Cricket Players

An understanding of the relationship between performance and physiology is essential for devising match-specific and effective conditioning training programs. Initially, Fletcher (1955) suggested that a greater physiological demand (based on energy expenditure) resulted from walking at 6.4 km·h⁻¹ than a typical day’s play during a multi-day (test) match. However, since this original study, numerous studies have reported on the physiological demands of all three cricket match formats, with the resultant data demonstrating conflicting results. As with the physical demands of cricket players, the information outlined in the following section would be useful in the development of conditioning programs for cricket players for a match-specific training response.

Match Physiological Responses of Medium-Fast Bowlers

Despite the increase in information reporting the physiological demands of cricket, only Petersen et al. (2010) have reported on the HR responses of elite medium-fast bowlers during a match. This study reported $HR_{\text{mean}}$ and $HR_{\text{max}}$ values of $133 \pm 12$ b·min⁻¹ and $181 \pm 10$ b·min⁻¹ during a T20 match, respectively. Unfortunately, this is the only information regarding the physiological responses of medium-fast bowlers during cricket match-play and therefore may not demonstrate the typical cardiovascular response during match-play. Therefore, more research is required to examine the physiological (HR, $[BLa^+]$) and perceptual) responses across all match formats in order to replicate match intensity during training.
Training Physiological Responses of Medium-Fast Bowlers

The HR responses of medium-fast bowlers during match-simulation protocols and net-based training sessions have been more thoroughly investigated (Burnett, Elliott & Marshall, 1995; Duffield et al., 2009; Stretch & Lambert, 1999). This HR data has helped to demonstrate that the physiological responses to cricket training are highly intermittent and require periods of HI activity to be fuelled through anaerobic metabolism. In the study of Burnett et al. (1995), the HR$_{\text{mean}}$ of medium-fast bowlers was $171 \pm 10 \, \text{b.min}^{-1}$, although throughout a 12-over bowling spell this ranged from $163-176 \, \text{b.min}^{-1}$. Similarly, Stretch and Lambert (1999) reported that medium-fast bowlers possessed a highly variable HR throughout a 6-over bowling spell in the nets, which ranged between $146-156 \, \text{b.min}^{-1}$, with a HR$_{\text{mean}}$ of $153 \pm 10 \, \text{b.min}^{-1}$. However, it is unlikely that medium-fast bowlers will complete 12 overs during a single spell during a typical cricket match. In order to understand the changes in physiological response during repeated medium-fast bowling spells, Duffield et al. (2009) reported on the HR responses (along with numerous other physiological responses) of a cohort of elite players during a 2 x 6-over bowling spell. Following each 6-over spell, Duffield et al. (2009) reported a HR$_{\text{mean}}$ of $162 \pm 9 \, \text{b.min}^{-1}$ and $162 \pm 12 \, \text{b.min}^{-1}$ for spells 1 and 2, respectively. This research demonstrates that the intermittent physiological intensity of medium-fast bowling was evident as in previous research (see Figure 2.1, over the page). It should also be noted that the HR$_{\text{mean}}$ reported during this match-simulation was considerably higher than that reported for actual match-play (Petersen et al., 2010), despite the protocol being designed to replicate a typical cricket match. Therefore, it could be argued that the current protocols used to
quantify the HR responses of medium-fast bowlers are not replicable of a typical match and as such, do not provide a match-specific response.

![Graph](image)

**Figure 2.1:** Heart rate before (pre) and after ball 6 (B6) of each over of a 12-over spell of medium-fast bowling (mean ± SD) (Duffield et al., 2009).

Separately, Burnett et al. (1995) reported that throughout a 12-over spell, the [BLa⁻] of the medium-fast bowlers ranged between 4.4-5.1 mmol·L⁻¹. In addition, Duffield and colleagues (2009) reported similar values when the bowling spell was divided into two separate spells of 6 overs (4.7-5.0 mmol·L⁻¹). Therefore, given this moderate increase in [BLa⁻], it is suggested that the resultant decrease in pH that results from anaerobic metabolism is insufficient to result to affect performance within medium-fast bowlers. While bowlers perform a HI effort as part of their run-up (5.7 ± 0.5 m·s⁻¹) prior to releasing each delivery, there is an active recovery period of 20-30 s to allow them to walk back to their starting position following each delivery (Burnett et al., 1995). Accordingly, Duffield et al. (2009) reported that bowlers with a faster run-up speed possessed a higher [BLa⁻], which most likely is due to the higher requirement for anaerobic metabolism. Separately, Duffield et al. (2009) also reported on the
perceptual responses of medium-fast bowlers reporting RPE values of 6.5 ± 0.8 (CR-10 scale) following a 2 x 6-over bowling spell in a match-simulation protocol. While no significant difference ($p > 0.05$) was present between spells, Duffield et al. (2009) reported a trend ($d = 0.8$) existed for a higher RPE following the second bowling spell. Similarly, Delvin, Fraser, Barras and Hawley (2001) reported a similar relative RPE (11-15 using the 20-point scale) following 2 x 6-over spells. Based on this, Duffield et al. (2009) suggested that medium-fast bowlers displayed an increased level of perceptual fatigue, despite no increase in physiological intensity during repeat bowling spells, suggesting other physiological capacities such as heat storage, substrate availability or muscle damage may play a role. Given the variability in the physiological intensities associated with medium-fast bowling, it is important that the current training and simulated match protocols must replicate these intensities if similar physiological responses are to be gained.

**Match Physiological Responses of Batsmen**

Previous research into the physiological responses of batsmen during a cricket match is limited however, it is apparent that greater HR responses occur during the shorter match formats (Nicholson et al., 2009; Petersen et al., 2010). For example, during OD match-play, a batsman’s HR$_{\text{mean}}$ ranges between 139-154 b·min$^{-1}$, which increases to 149-167 b·min$^{-1}$ for T20 matches (Nicholson et al., 2009; Petersen et al., 2010). Nicholson et al. (2009) suggested that this is due to the greater amount of time spent performing HI activities such as striding and sprinting during a T20 match, as opposed to a OD match. As such, T20 batsmen spend significantly ($p = 0.021$) more time working at HI’s (>85%
HR_{max} when compared to OD batsmen (T20: 53.1 ± 24.2%; OD: 19.7 ± 6.9%, respectively), which is combined with significantly less time in recovery or rest (<70% HR_{max}) (p = 0.015). Within this study, Nicholson et al. (2009) noted that the intensity was highly variable and is greatly influenced by factors such as the match format, match situation and the individual. This makes it difficult for coaches looking to devise specific conditioning program aimed at improving the fitness level of batsmen. Despite the limited data, Nicholson et al. (2009) suggested that given the large contribution from the anaerobic energy systems, the inclusion of repeated sprint activities may lead to a match-specific conditioning response.

**Training Physiological Responses of Batsmen**

Several studies have also reported on the HR responses of batsmen during match-simulated batting protocols and different training methods (Christie & King, 2008; Christie et al., 2008; Houghton et al., 2011a; Houghton et al., 2011b). The individual nature of each study and variations across match formats make inter-study comparisons difficult. For example, Christie et al. (2008) developed a batting simulation that required batsmen to face 42 deliveries from a bowler and complete two runs every third ball faced. In this study, the researchers reported a HR_{mean} of 145 ± 11 b\text{min}^{-1}. This is similar to the HR_{mean} (123-153 b\text{min}^{-1}) reported by Houghton et al. (2011a; 2011b) throughout the BATEX protocol. However, regardless of the protocol used to assess or train batsmen, there is a tendency for HR to increase throughout each simulation (Christie et al., 2008; Houghton et al., 2011a; Houghton et al., 2011b).
Separately, the [BLa] of batsmen during the BATEX protocol employed by Houghton et al. (2011a), ranged between 3.2-4.5 mmol·L⁻¹, and appeared dependent on the theoretical batting stage being completed. Additionally, Houghton et al. (2011a; 2011b) reported on the perceptual responses of batsmen during the BATEX training protocol whereby, greater RPE scores were matched with an increase in the relative distance covered each hour and HR<sub>mean</sub>. As previously stated, no information regarding the physiological intensities involved with net-based or other training formats currently exist. As previously stated this makes it difficult to develop batting specific conditioning programs. Given the HI yet sporadic nature of cricket batting, a training method that replicates this is more likely to create a physiologically demanding training environment where skill can be developed under fatigue.

**Training Physiological Responses of Other Playing Positions**

Although Petersen et al. (2010) has reported on the physiological responses of spin bowlers, fielders and wicketkeepers during competitive cricket matches, no information currently exists on the physiological responses associated with any form of training or match-simulated protocols including spin bowlers, fielders or wicketkeepers. As such it is difficult to determine if the current training formats used to condition these players validly replicate the physiological demands of a typical cricket match. Therefore, it is not surprising that future studies must further quantify the physiological responses not only of medium-fast bowlers and batsmen, but rather all playing positions.
Summary of the Physiological Demands of Cricket

As with the physical demands of cricket, the resulting physiological demands are HI and intermittent in nature. For example, the HR of medium-fast bowlers can vary by approximately 10 b·min^{-1} throughout a bowling spell, which reflects the constant variation between HI and LI activity. Despite the intermittent nature of these responses within each playing position, it is apparent that the game or training format has a considerable influence on the physiological load of players. The evidence suggests that the fewer overs played during a match is correlated with a greater physiological intensity despite the shorter duration. Both medium-fast bowlers and batsmen reported a considerably greater HR_{mean} during T20 matches when compared to that of OD matches. Further to this, it is unclear if the current training techniques or testing protocols used by both coaches and researchers are match-specific as the current literature shows that these are performed at a greater intensity than that of a typical cricket match. As such, more detail is required to better understand the physical and physiological responses of cricket players and apply this to cricket-specific conditioning and training programs.

Specificity of Game-Based Training

The principle of specificity states that for optimal adaptation and improvement in performance, training should aim to replicate the physiological demands and movements patterns of match-play as closely as possible (Reilly, Morris & Whyte, 2009; Rushall & Pyke, 1990). Within a team sport environment, it is the role of coaching staff to develop training sessions which provide a sufficient physiological stimulus to replicate typical match-play (Farrow, Pyne & Gabbett,
In order to replicate these match demands, coaches have employed game-based training protocols designed to simulate the physical, physiological and technical demands of team sports within a competitive environment (Gabbett et al., 2009). The advantage of this game-based method is that it allows players to train in situations that offer similarity to typical match-play, and be exposed to additional factors such as game pressure and fatigue, which are not normally associated with closed training drills (Farrow et al., 2008; Gabbett, 2002). Importantly, Farrow et al. (2008) reported that game-based training or ‘open’ drills amongst Australian Football players allowed a greater relative intensity of training when compared to that of closed drills (repetitious drills focused on skill execution) (mean speed: 90 ± 22 m min⁻¹; 78 ± 10 m min⁻¹; HR\text{mean}: 178 ± 5 b min⁻¹; 165 ± 11 b min⁻¹, respectively). However, for these open training sessions to be ecologically valid, they must replicate the specific match demands of a particular sport. Despite numerous studies reporting on the use of game-based training (Gabbett et al., 2009; Gabbett, 2008; Hoff, Wisloff, Engen, Kemi & Helgerud, 2002), few studies have made comparisons to actual match demands. One study from Gabbett (2003) reported similar physiological demands (HR\text{mean}: 155 b min⁻¹; 152 b min⁻¹ and [BLa⁺]: 5.2 mmol L⁻¹; 5.2 mmol L⁻¹) between competitive matches and skill-based conditioning training, respectively in sub-elite rugby league players. Due to these similarities, it was put forward that players could concurrently develop both physiological capacities and technical elements. Furthermore, data from Farrow et al. (2008) demonstrated that game-based drills resulted in a considerably greater decision-making volume (game-based drills: 5.9 ± 1.4 AU; closed drills: 0 AU), whereas closed drills led to a greater volume of technical
attributes performed per session (handball volume: game-based drills: 4.6 ± 1.6; closed drills: 10.4 ± 1.7). Therefore, it is for coaching staff to ensure that game-based training provides sufficient physiological stimulus, whilst ensuring technical skill is developed within a match-specific environment. As the current point in time, SSG represent a popular game-based training method that replicates the match demands of various team sports, and their use will be discussed in depth on the following sections.

Description of Small-Sided Games

Small-sided games have become a common training format, typically used in team sports such as soccer and rugby league (Foster, Twist, Lamb & Nicholas, 2010; Hill-Haas et al., 2010). As described in Hill-Haas, Dawson, Impellizzeri and Coutts (2011), SSG are modified games used as a training method which are played on a reduced area, and may involve either adapted playing rules and/or a smaller number of players than a typical match. Previous research suggests SSG provide a physical and technical training stimulus that replicates the demands of FBTS (Davids et al., 2013; Gabbett et al., 2009). Due to the increasing popularity of SSG, the factors which influence the physiological responses, physical and technical demands and their effectiveness is well documented (Dellal et al., 2011a; Hill-Haas et al., 2010; Hill-Haas et al., 2009b; Kelly & Drust, 2009; Mallo & Navarro, 2008). Typically, FBTS such as soccer and rugby league have been the focus of SSG research to date, although new studies have examined the physical, physiological and technical demands associated with other team sports (Davies, Young, Farrow & Bahnert, 2013; Kennett, Kempton & Coutts, 2012; Sampaio, Abrantes & Leite, 2009).
Factors Influencing Small-Sided Games

While SSG aim to replicate match intensities and environments, subtle manipulations of match constraints are able to vary training demands (Gabbett et al., 2009). In recent times, several studies have reported that changes to the playing rules as well as the size of the field or the number of players involved can significantly influence the physiological, physical and technical demands placed upon athletes whilst competing within SSG (Casamichana & Castellano, 2010; Dellal et al., 2011a; Gabbett et al., 2012a; Hill-Haas et al., 2010; Hill-Haas et al., 2009b; Kelly & Drust, 2009).

Number of Players

The consensus amongst the current research suggests that reducing the number of players significantly increases the physiological demands of athletes (see Table 2.4, page 37) (Hill-Haas et al., 2010; Hill-Haas et al., 2009b; Impellizzeri et al., 2006; Jones & Drust, 2007; Katis & Kellis, 2009; Sampaio et al., 2009). In particular, studies from both Hill-Haas et al. (2009b) and Rampinini et al. (2007) reported that a higher HR_{max} is reached during SSG that is played with fewer elite soccer players. Furthermore, a reduction in the number of players in SSG training has also been shown to increase other physiological markers of physiological intensity, such as [BLa']. Lastly, an increase in player number appears to also reduce the RPE reported during soccer-specific SSG (Little & Williams, 2007; Rampinini et al., 2007). It has been suggested that this reduction in RPE with an increasing number of players is the result of a reduced time in possession with the football and/or players, and increased space to move (Hill-Haas et al., 2009b). Taken together, it appears that fewer players per
playing area result in an increased physiological stimulus, which reflects changes within the physical demands.

In regards to the physical demands of athletes during SSG training (Table 2.5, page 38), the results suggest that the number of players on the field does not significantly influence the movement demands (Hill-Haas et al., 2010; Hill-Haas et al., 2009b; Jones & Drust, 2007; Randers et al., 2010). In particular, Jones and Drust (2007) reported no significant differences ($p > 0.05$) between elite male soccer players during 4 v 4 ($778 \pm 160$ m) and 8 v 8 ($693 \pm 103$ m) SSG formats. Further, the total distance covered whilst walking, jogging and sprinting did not differ between the two game formats (Jones & Drust, 2007). It was suggested this was due to players being in possession of the ball more often and therefore slowing down to control the ball. In contrast to this, Kennett et al. (2012) reported an increase in physical demands during rugby-union SSG when the number of players was decreased (mean speed and number of sprints: 4 v 4: $114 \pm 16$ m min$^{-1}$ and $2.1 \pm 3.6$; 6 v 6: $110 \pm 15$ m min$^{-1}$ and $1.4 \pm 1.8$; 8 v 8: $100 \pm 16$ m min$^{-1}$ and $1.0 \pm 1.2$; respectively). Taken together, these results suggest that the physical responses associated with changes in player numbers are highly variable and may be influenced by other factors such as the size of the playing field and specific demands of the sport.
Table 2.4: Summary of studies examining the physiological responses to changes in player numbers during small-sided games (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Number of Players</th>
<th>Peak %HR$_{max}$</th>
<th>[BLa] (mmol L$^{-1}$)</th>
<th>RPE (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rampinini et al. (2007)</td>
<td>20 amateur soccer players</td>
<td>3 v 3</td>
<td>89.4 ± 2.3</td>
<td>5.5 ± 1.6</td>
<td>7.6 ± 0.9*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 v 4</td>
<td>88.0 ± 2.6</td>
<td>5.0 ± 1.7</td>
<td>7.2 ± 0.9*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 v 5</td>
<td>87.4 ± 3.5</td>
<td>4.8 ± 1.6</td>
<td>6.8 ± 1.0*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 v 6</td>
<td>85.7 ± 3.4</td>
<td>4.2 ± 1.6</td>
<td>6.3 ± 1.2*</td>
</tr>
<tr>
<td>Hill-Haas et al. (2010)</td>
<td>16 youth soccer players</td>
<td>3 v 3</td>
<td>82.3 ± 3.5</td>
<td>2.5 ± 0.7</td>
<td>16.3 ± 1.6*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 v 4</td>
<td>83.1 ± 4.0</td>
<td>2.5 ± 0.9</td>
<td>14.6 ± 1.5*</td>
</tr>
<tr>
<td>Hill-Haas et al. (2009b)</td>
<td>16 soccer players</td>
<td>2 v 2</td>
<td>89.0 ± 4.0</td>
<td>6.7 ± 2.6</td>
<td>13.1 ± 1.5*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 v 4</td>
<td>85.0 ± 4.0</td>
<td>4.7 ± 1.6</td>
<td>12.2 ± 1.8*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 v 6</td>
<td>83.0 ± 4.0</td>
<td>4.1 ± 2.0</td>
<td>10.5 ± 1.5*</td>
</tr>
<tr>
<td>Katis and Kellis (2009)</td>
<td>34 amateur, youth soccer players</td>
<td>3 v 3</td>
<td>88.6 ± 4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 v 6</td>
<td>82.8 ± 3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampaio et al. (2009)</td>
<td>8, youth basketball players</td>
<td>3 v 3</td>
<td>87.1 ± 1.5</td>
<td></td>
<td>3.0 ± 1.1*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 v 4</td>
<td>82.7 ± 1.6</td>
<td></td>
<td>4.1 ± 1.0*</td>
</tr>
<tr>
<td>Foster et al. (2010)</td>
<td>22 youth rugby league players</td>
<td>4 v 4</td>
<td>88.1 ± 4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 v 6</td>
<td>89.3 ± 4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kennett et al. (2012)</td>
<td>20 semi-professional rugby union players</td>
<td>4 v 4</td>
<td>88.8 ± 5.9</td>
<td>8.9 ± 3.2</td>
<td>17.4 ± 1.5*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 v 6</td>
<td>88.4 ± 5.7</td>
<td>6.5 ± 3.0</td>
<td>15.0 ± 1.8*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 v 8</td>
<td>87.1 ± 5.1</td>
<td>6.0 ± 3.7</td>
<td>12.7 ± 2.5*</td>
</tr>
</tbody>
</table>

* CR-10 RPE scale; † Borg’s 15 Point (6-20) RPE scale.
Table 2.5: Summary of studies examining the physical demands to changes in player numbers during small-sided games (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Number of Players</th>
<th>Total Distance (m·h⁻¹)</th>
<th>H1 Total Distance (m·h⁻¹)</th>
<th>Mean Speed (m·min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jones and Drust (2007)</td>
<td>8 elite youth soccer players</td>
<td>4 v 4 8 v 8</td>
<td>4668 ± 960</td>
<td>4158 ± 618</td>
<td>102 ± 7</td>
</tr>
<tr>
<td>Hill-Haas et al. (2010)</td>
<td>16 youth soccer players</td>
<td>3 v 4 5 v 6</td>
<td>6098 ± 415</td>
<td>1128 ± 500 6178 ± 888 1563 ± 513</td>
<td>103 ± 15 102 ± 7</td>
</tr>
<tr>
<td>Hill-Haas et al. (2009b)</td>
<td>16 soccer players</td>
<td>2 v 2 4 v 4 6 v 6</td>
<td>6435 ± 40</td>
<td>1028 ± 33 1090 ± 38 1105 ± 55</td>
<td>145 ± 10 168 ± 13 166 ± 15</td>
</tr>
<tr>
<td>Dellal et al. (2011b)</td>
<td>20 elite soccer players</td>
<td>2 v 2 3 v 3 4 v 4</td>
<td>8683 ± 623</td>
<td>1841 ± 284 2113 ± 167 1810 ± 267</td>
<td>114 ± 16 110 ± 15 100 ± 16</td>
</tr>
<tr>
<td>Kennet et al. (2012)</td>
<td>20 semi-professional rugby union players</td>
<td>4 v 4 6 v 6 8 v 8</td>
<td>901 ± 591</td>
<td>657 ± 426 505 ± 380</td>
<td>114 ± 16 110 ± 15 100 ± 16</td>
</tr>
</tbody>
</table>
**Field Size**

Data demonstrates the demands of SSG can also be altered through changing the dimensions of the playing field. The research examining the physiological responses and physical demands associated with alterations to the field dimensions during SSG have to date provided equivocal results. Rampinini et al. (2007) and Köklü, Albayrak, Keysan, Alemdaroğlu and Dellal (2013) suggested that soccer SSG played on larger fields produce a higher physiological intensity than the same drills being performed on smaller fields. Casamichana and Castellano (2010) expanded on this by varying the approximate individual playing area of each player during 5 v 5 soccer SSG. In line with previous studies, an increase in soccer player’s physiological responses (Table 2.6, page 41) and physical demands resulted from an increase in field size. However, these results contradict those of both Kelly and Drust (2009) and Foster et al. (2010) who both reported that changes in field size had no significant ($p > 0.05$) impact on the HR responses of soccer players. Further, Tessitore, Meesusen, Piacentini, Demarie and Capranica (2006) reported that the highest physiological intensities are achieved whilst playing SSG on smaller soccer fields rather than larger fields. At present, few studies have examined the influence of changes to the playing field size on an athlete’s physical demand. In most cases, the size of the playing area increases with the addition of an extra player such as that within the study of Dellal et al. (2011a). As a result of this, it remains unclear what effect on an athlete’s movement patterns can result from changing the size of the playing area during SSG training. Furthermore, an underlying factor which does not allow for a consensus on the intensity levels and demands in SSG is the difference in field
sized used in opposing studies, combined with other factors such as the number of players or the use of different match rules.

Variation to the Playing Rules

The manipulation of SSG constraints to influence the intensity of a training session is not limited to simply changing the number of players involved or the size of the playing area. Several studies have also investigated the effect of modifying the playing rules (Aroso, Rebelo & Gomes-Pereira, 2004; Hill-Haas et al., 2010; Little & Williams, 2007; Tessitore et al., 2006). In their review, Hill-Haas et al. (2011) summarised the effect of rule changes in SSG on HR, [BLa] and the perceptual responses in FBTS athletes. The influence of rule changes on the physical demands has also been reported in previous research as seen in Table 2.7 (page 42). Specifically, changes made to playing rules can increase the total distance covered, as well as the distance covered whilst sprinting or performing at a HI (Table 2.8, see page 43).
Table 2.6: Summary of studies examining the physiological responses to changes in field size during small-sided games (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Field Size (m)</th>
<th>Peak %HR&lt;sub&gt;max&lt;/sub&gt;</th>
<th>[BLa&lt;sub&gt;−&lt;/sub&gt;] (mmol L&lt;sup&gt;−1&lt;/sup&gt;)</th>
<th>RPE (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rampinini et al. (2007)&lt;sup&gt;Δ&lt;/sup&gt;</td>
<td>20 amateur soccer players</td>
<td>Small Medium Large</td>
<td>87.0 ± 3.6</td>
<td>4.6 ± 1.6</td>
<td>6.7 ±1.2*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 x 20</td>
<td>91.0 ± 4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kelly and Drust (2009)</td>
<td>8 professional soccer players</td>
<td>40 x 30 50 x 40</td>
<td>90.0 ± 4.0</td>
<td>4.9 ± 1.6</td>
<td>7.1 ±1.1*</td>
</tr>
<tr>
<td>Foster et al. (2010)</td>
<td>22 rugby league players</td>
<td>15 x 25 20 x 30 25 x 35</td>
<td>88.2 ± 3.9</td>
<td>5.1 ± 1.7</td>
<td>7.2 ±1.1*</td>
</tr>
<tr>
<td>Casamichana and Castellano (2010)</td>
<td>10 youth soccer players</td>
<td>32 x 23 50 x 35 62 x 44</td>
<td>93.0 ± 5.7</td>
<td>6.7 ± 1.0*</td>
<td></td>
</tr>
<tr>
<td>Kennett et al. (2012)</td>
<td>20 semi-professional rugby union players</td>
<td>32 x 24 64 x 48</td>
<td>86.7 ± 6.0</td>
<td>5.7 ± 3.3</td>
<td>13.7 ±2.7*</td>
</tr>
<tr>
<td>Köklü et al. (2013)</td>
<td>16 elite youth soccer players</td>
<td>20 x 20 30 x 20 32 x 25</td>
<td>86.5 ± 4.0</td>
<td>4.4 ± 0.5*</td>
<td></td>
</tr>
</tbody>
</table>

<sup>Δ</sup>Field size varied with number of players in field therefore average taken from all three field sizes; *CR-10 RPE scale; *Borg’s 15 Point (6-20) RPE scale.
Table 2.7: Summary of studies examining the physiological responses to changes in the playing rules during small-sided games (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Player Number</th>
<th>Rules</th>
<th>%HR&lt;sub&gt;max&lt;/sub&gt; (%)</th>
<th>[BLa] (mmol.L⁻¹)</th>
<th>RPE (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hill-Haas et al. (2010)</td>
<td>16 youth soccer players</td>
<td>3 v 4 and 3 v 3 + 1 floater</td>
<td>a + b</td>
<td>83.3 ± 3.8</td>
<td>2.8 ± 1.0</td>
<td>15.8 ± 1.6*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 v 4 and 3 v 3 + 1 floater</td>
<td>a + b + c</td>
<td>84.8 ± 3.8</td>
<td>2.4 ± 0.8</td>
<td>15.6 ± 2.3*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 v 4 and 3 v 3 + 1 floater</td>
<td>a + b + c + d</td>
<td>80.3 ± 4.8</td>
<td>2.3 ± 1.1</td>
<td>14.8 ± 1.2*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 v 4 and 3 v 3 + 1 floater</td>
<td>a + b + c + d + e</td>
<td>83.7 ± 4.0</td>
<td>2.8 ± 1.1</td>
<td>15.1 ± 1.6*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 v 6 and 5 v 5 + 1 floater</td>
<td>a + b</td>
<td>81 ± 4</td>
<td>2.2 ± 1.0</td>
<td>15.3 ± 1.1*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 v 6 and 5 v 5 + 1 floater</td>
<td>a + b + c</td>
<td>83 ± 5</td>
<td>3.2 ± 1.2</td>
<td>14.9 ± 1.4*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 v 6 and 5 v 5 + 1 floater</td>
<td>a + b + c + d</td>
<td>83 ± 5</td>
<td>2.3 ± 1.1</td>
<td>14.6 ± 0.9*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 v 6 and 5 v 5 + 1 floater</td>
<td>a + b + c + d + e</td>
<td>80 ± 3</td>
<td>2.4 ± 0.9</td>
<td>14.9 ± 1.1*</td>
</tr>
<tr>
<td>Dellal et al. (2011a)</td>
<td>20 elite soccer players</td>
<td>2 v 2</td>
<td>One touch</td>
<td>90.3 ± 2.6</td>
<td>3.9 ± 0.3</td>
<td>8.2 ± 0.7*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 v 2</td>
<td>Two touch</td>
<td>90.1 ± 2.2</td>
<td>3.5 ± 0.3</td>
<td>7.7 ± 0.6*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 v 2</td>
<td>Free play</td>
<td>90.0 ± 2.3</td>
<td>3.4 ± 0.2</td>
<td>7.6 ± 0.6*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 v 2</td>
<td>One touch</td>
<td>90.0 ± 2.4</td>
<td>3.8 ± 0.4</td>
<td>8.1 ± 0.7*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 v 3</td>
<td>Two touch</td>
<td>89.3 ± 2.8</td>
<td>3.3 ± 0.5</td>
<td>7.9 ± 0.7*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 v 3</td>
<td>Free play</td>
<td>89.6 ± 2.2</td>
<td>3.0 ± 0.5</td>
<td>7.5 ± 0.5*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 v 3</td>
<td>One touch</td>
<td>87.6 ± 2.5</td>
<td>2.9 ± 0.3</td>
<td>8.0 ± 0.7*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 v 4</td>
<td>Two touch</td>
<td>85.6 ± 2.9</td>
<td>2.8 ± 0.1</td>
<td>7.9 ± 0.8*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 v 4</td>
<td>Free play</td>
<td>84.7 ± 2.7</td>
<td>2.9 ± 0.2</td>
<td>7.2 ± 0.5*</td>
</tr>
</tbody>
</table>

a: offside rule in effect (front one-third zone of the pitch); b: kick in only (ball cannot be thrown in if it leaves the pitch); c: all attacking team players must be in front 2 zones for a goal to count; d: outside, but along the 2 lengths of each pitch, 2 neutral players can move up and down the pitch but not enter the grid. Before a shot on goal is permitted, the attacking team must pass the ball to either player in the defensive half. Each player is only allowed a maximum of 1 touch on the ball; e: 1 player from each team ("a pair") completes 4 repetitions of 'sprint the widths/jog the lengths' on a 90-second interval (3 v 4 and 3 v 3 + 1 floater games) or 3 repetitions on an 80-second Interval (5 v 6 and 5 v 5 + 1 floater games); *CR-10 RPE scale; "Borg’s 15 Point (6-20) RPE scale."
Table 2.8: Summary of studies examining the physical demands to playing rule changes during small-sided games (mean ± SD).

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Player Number</th>
<th>Rules</th>
<th>Total Distance (m h⁻¹)</th>
<th>HI Total Distance (m h⁻¹)</th>
<th>Mean Speed (m min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallo and Navarro (2008)</td>
<td>10 elite soccer players</td>
<td>3 v 3</td>
<td>Keep possession</td>
<td>8964 ± 288</td>
<td>8988 ± 348</td>
<td>7657 ± 408</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Keep possession with 2 neutral players</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ordinary rules with goalkeeper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hill-Haas et al. (2010)</td>
<td>16 youth soccer players</td>
<td>3 v 4 and 3 v 3 + 1 floater</td>
<td>a + b</td>
<td>6098 ± 415</td>
<td>1128 ± 500</td>
<td>102 ± 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b + c</td>
<td>6013 ± 503</td>
<td>108 ± 325</td>
<td>100 ± 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b + c + d</td>
<td>6125 ± 558</td>
<td>1130 ± 363</td>
<td>102 ± 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b + c + d + e</td>
<td>6693 ± 480</td>
<td>1895 ± 360</td>
<td>112 ± 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b</td>
<td>6178 ± 888</td>
<td>1563 ± 513</td>
<td>103 ± 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b + c</td>
<td>6345 ± 368</td>
<td>1488 ± 318</td>
<td>108 ± 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b + c + d</td>
<td>6535 ± 445</td>
<td>1288 ± 370</td>
<td>109 ± 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a + b + c + d + e</td>
<td>6598 ± 465</td>
<td>1828 ± 278</td>
<td>110 ± 8</td>
</tr>
<tr>
<td>Dellal et al. (2011a)</td>
<td>20 elite soccer players</td>
<td>2 v 2</td>
<td>One touch</td>
<td>9795 ± 4650</td>
<td>2475 ± 221</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two touch</td>
<td>9090 ± 540</td>
<td>2035 ± 290</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Free play</td>
<td>8685 ± 623</td>
<td>1841 ± 284</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>One touch</td>
<td>11240 ± 785</td>
<td>2616 ± 281</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two touch</td>
<td>10625 ± 860</td>
<td>2370 ± 234</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Free play</td>
<td>10070 ± 775</td>
<td>2112 ± 167</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>One touch</td>
<td>11464 ± 938</td>
<td>2396 ± 211</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two touch</td>
<td>10556 ± 825</td>
<td>2108 ± 249</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Free play</td>
<td>9990 ± 889</td>
<td>1810 ± 267</td>
<td></td>
</tr>
</tbody>
</table>

a: offside rule in effect (front one-third zone of the pitch); b: kick in only (ball cannot be thrown in if it leaves the pitch); c: all attacking team players must be in front 2 zones for a goal to count; d: outside, but along the 2 lengths of each pitch, 2 neutral players can move up and down the pitch but not enter the grid. Before a shot on goal is permitted, the attacking team must pass the ball to either of these players. The ball can also be passed to either player in the defensive half. Each player is only allowed a maximum of 1 touch on the ball; e: 1 player from each team (“a pair”) completes 4 repetitions of ‘sprint the widths/jog the lengths’ on a 90-second interval (3 v 4 and 3 v 3 + 1 floater games) or 3 repetitions on an 80-second interval (5 v 6 and 5 v 5 + 1 floater games).
Influence on the Technical Demands during Small-Sided Games

Despite the vast majority of research reporting on the physical and physiological demands of SSG (Casamichana, Castellano & Castagna, 2012; Dellal et al., 2011a; Dellal et al., 2008; Foster et al., 2010; Hill-Haas et al., 2010; Hill-Haas, Rowsell, Dawson & Coutts, 2009c; Kelly & Drust, 2009; Sampaio et al., 2009), they are also used by coaches as a tool for improving an athlete’s technical proficiency (Davids et al., 2013). Research regarding the technical actions of athletes during SSG is increasing, although the majority of available literature has again focused on SSG used in soccer (Dellal, Lago-Penas, Wong del & Chamari, 2011c; Fradua et al., 2012; Gabbett et al., 2012a; Jones & Drust, 2007; Klusemann, Pyne, Foster & Drinkwater, 2012; Owen, Twist & Ford, 2004; Tessitore et al., 2006).

Much of the research has examined the influence of alterations to the field size, player number and number of ball contacts allowed, with the current literature reporting mixed results (Dellal et al., 2011c; Fanchini et al., 2011; Gabbett et al., 2012a; Jones & Drust, 2007; Kelly & Drust, 2009; Owen et al., 2004). Expectedly, Owen et al. (2004) reported that fewer technical actions (pass, receive, dribble, turn and header) were performed by each individual player when the number of players on the field was increased. Alternatively, an increase in field size showed little effect on the number of technical actions performed. Similarly, Jones and Drust (2007) reported an increase in the number of ball contacts made by each player when the number of players
involved was increased. Klusemann et al. (2012) reported a similar effect of player number on the amount of technical skills performed during basketball SSG, as the manipulation of player numbers had a greater impact on the technical demands (dribbling, rebounds, close range shots) than either changing court size or work-to-rest ratio. In contrast, Casamichana and Castellano (2010) observed a significant increase in the frequency of motor behaviours such as interceptions (small: 11.2 ± 3.1; large: 6.3 ± 1.5), clearances (small: 8.0 ± 2.9; medium: 3.8 ± 2.6; large: 2.3 ± 1.0) and putting the ball in play (small: 27.7 ± 3.8; medium: 16.5 ± 1.6; large: 12.2 ± 4.3), with a decrease in playing area and suggested that the size of the playing field largely determines a player’s technical behaviour during SSG.

Recently, a small number of studies have also reported on the quality of the technical skills performed during soccer SSG (Dellal et al., 2011c; Fanchini et al., 2011; Gabbett et al., 2012a). These data demonstrate that the quality of technical actions, such as the percentage of successful passes or number of lost balls can be influenced through manipulating SSG rules and playing format. For example, Dellal et al. (2011a) reported the lowest number of successful passes and the greatest number of balls lost in possession occurred when the players were only allowed one touch per possession, regardless of the playing format. Furthermore, Dellal et al. (2011c) also reported a significant difference in these measures between consecutive training bouts within a training session. Therefore, by manipulating the technical and physical demands of SSG, coaches create match-like situations in which players are provided with a suitable conditioning and technical training stimuli.
Variability and Reproducibility of Small-Sided Games

Past data has also demonstrated that SSG provide sufficient physiological, physical and technical training stimulus (Gabbett et al., 2009; Hill-Haas et al., 2011), however the reproducibility of these measures both between and within training sessions is important for coaches to interpret. Studies reporting on the variability and reliability of SSG have demonstrated that players are provided with a consistent training stimulus, most notably during sessions that involve a small number of players (Hill-Haas, Coutts, Rowsell & Dawson, 2008a; Hill-Haas, Rowsell, Coutts & Dawson, 2008b; Rampinini et al., 2007). Originally, Rampinini et al. (2007) reported that [BLa] was highly variable within each participant (CV: 21.8-39.2%) when compared to either HR (CV: 1.9-5.8%) or RPE (CV: 4.1-23.4%). In agreement with this, Hill-Haas et al. (2008a) demonstrated similar training responses between sessions, irrespective of the playing format (Typical Error as a percentage of the mean [TE%]: %HRmax: 1.9-4.4%; HRmax: 1.1-3.6%; RPE: 5.9-15.3%; [BLa]: 16.5-34.4%). It is likely that the greater variability of [BLa] was attributed to various factors, including the random nature of SSG and the methodology used during the study. Importantly, Hill-Haas et al. (2008b) showed that both [BLa] and distance travelled at speeds above 18 km·h⁻¹ were not reproducible, either within or between SSG training sessions. Taken together, these data demonstrate that SSG produce a consistent training stimulus, although some variability is evident in physical and physiological measures of HI activity. However, the only available research examining the reproducibility of SSG is limited to soccer players. Therefore, future research is required to examine the reproducibility of physiological and physical demands of SSG other than during those specific to soccer.
Furthermore, the reproducibility of the technical demands of skill-based sports also needs to be reported on.

**Comparison of Traditional Training and Small-Sided Games**

It has been suggested that activities which replicate the movements and metabolic conditions of actual match-play are most likely to be effective at improving match performance (Wallace, Slattery & Coutts, 2009). In the past, training protocols have involved interval training to improve soccer performance by enhancing aerobic endurance (Helgerud, Engen, Wisloff & Hoff, 2001). Alternatively, specially designed drills and small-group play have also been used as a substitute for traditional interval training (Gabbett et al., 2009). However, such training methods are limited for performance improvements given the difficulties with the successful incorporation of skill acquisition and practice (Gabbett et al., 2009; Williams & Hodges, 2005). The use of SSG facilitates an environment that provides both physiological and technical challenges. However, the physiological demands of SSG for all sports have not been comprehensively investigated.

To ensure sufficient metabolic conditioning, the physiological responses of SSG must resemble or exceed that typical of more traditional conditioning techniques such as interval or intermittent running. Dellal, et al. (2008) demonstrated that SSG produced a similar cardiovascular response (% HR reserve) to an intermittent running protocol in soccer players over a 7-week period.
Additionally, after 6 weeks of aerobic interval and SSG training Reilly and White (2007) reported no significant difference between [BLa] and maximum aerobic capacity (\(\dot{V}O_{2\text{max}}\)) within academy-level soccer players. Impellizeri et al. (2006) reported that after 8 weeks of either generic soccer conditioning or SSG, that no significant differences (\(p > 0.05\)) in specific measures, particularly aerobic power and capacity existed in junior soccer players (Table 2.9, page 49). Similarly, Hill-Haas et al. (2009a) reported no differences in the HR achieved or perceptual responses of elite, youth soccer players when performing a 7 week program of either generic running or SSG training.

There is evidence to suggest that SSG may provide a high level of aerobic conditioning (Sassi et al., 2004), as a greater HR\(_{\text{mean}}\) was reported during soccer SSG (174 ± 7 b\cdot min\(^{-1}\)) when compared to interval running (167 ± 4 b\cdot min\(^{-1}\)). Within junior soccer players, Radziminski, Rompa, Barnat, Dargiewicz and Jastrzebski (2013) demonstrated a significant increase in aerobic capacity (\(\dot{V}O_{2\text{max}}\)) following an 8 week soccer SSG regime (+4.7 ml\cdot kg\(^{-1}\)\cdot min\(^{-1}\)) in comparison to HI interval running (-0.9 ml\cdot kg\(^{-1}\)\cdot min\(^{-1}\)). Gamble (2004) demonstrated that after a 9 week skill-based rugby union SSG protocol, the %HR\(_{\text{max}}\) achieved at the end of the final stage of a multistage fitness test was significantly lower at weeks 4, 5 and 7 (\(p < 0.05\)) and week 9 (\(p < 0.01\)) when compared to the initial testing session. These studies demonstrate that SSG provided a suitable substitute for traditional conditioning programs that are required to encompass an aerobic training stimulus. However, as in most team sports a high level of aerobic fitness alone is not the only characteristic to be
competitive at the elite level; physiological and technical factors must also be developed.

**Table 2.9:** Effects of generic vs. small-sided soccer games training on junior soccer players (mean ± SD) (adapted from Impellizzeri et al., 2006).

<table>
<thead>
<tr>
<th>Training Format</th>
<th>Pre-Testing</th>
<th>After 4 weeks</th>
<th>After 8 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generic Training</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{max}}$ (ml kg$^{-1}$ min$^{-1}$)</td>
<td>55.6 ± 3.4</td>
<td>59.7 ± 4.1</td>
<td>60.2 ± 3.9</td>
</tr>
<tr>
<td>HR$_{\text{max}}$ (b min$^{-1}$)</td>
<td>197.7 ± 9.5</td>
<td>196.2 ± 10.0</td>
<td>194.1 ± 7.2</td>
</tr>
<tr>
<td>$\dot{V}O_2$ at Lactate Threshold (L min$^{-1}$)</td>
<td>45.1 ± 3.8</td>
<td>48.7 ± 3.3</td>
<td>50.9 ± 2.9</td>
</tr>
<tr>
<td><strong>Small-Sided Games</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{max}}$ (ml kg$^{-1}$ min$^{-1}$)</td>
<td>57.7 ± 4.2</td>
<td>61.4 ± 4.6</td>
<td>61.8 ± 4.5</td>
</tr>
<tr>
<td>HR$_{\text{max}}$ (b min$^{-1}$)</td>
<td>194.5 ± 7.1</td>
<td>192.9 ± 8.2</td>
<td>192.7 ± 8.9</td>
</tr>
<tr>
<td>$\dot{V}O_2$ at Lactate Threshold (L min$^{-1}$)</td>
<td>47.3 ± 4.9</td>
<td>50.7 ± 3.2</td>
<td>52.4 ± 2.8</td>
</tr>
</tbody>
</table>

Current research has reported that SSG may also be used in the development of other physiological and technical measures. Gabbett (2006) examined the effect traditional conditioning and skill-based conditioning games programs had on the lower body muscular power (vertical jump), speed (10, 20 and 40 m), agility (L-run), and maximal aerobic power (multi-stage fitness test) of sub-elite rugby league players. The researchers reported that greater improvements were observed in speed and muscular power, combined with similar improvements in agility and maximal aerobic power occurred as a result of SSG training, when compared to traditional conditioning training activities (continuous and intermittent running without the ball). Gabbett (2006) suggested that these improvements following SSG were reflective of the greater TL imposed due to the greater injury potential of the TCT activities. In comparison, Gabbett (2006) suggested that movements in SSG are less rigid than that of traditional training and are more representative of match movements. Importantly, Gabbett (2002)
has previously identified that a higher incidence of injuries occurred as a result of traditional conditioning training (37.5%), as opposed to SSG (10.7%). Therefore, the use of SSG may allow players to adhere to a greater number of training sessions, providing them opportunity to complete greater physical work and facilitate physiological adaptation.

**Summary of Small-Sided Games**

As research into the effectiveness of SSG is relatively new, there is limited information available that can be used to design training programs. As stated by Gabbett et al. (2009), the available evidence suggests that SSG training, regardless of which sport; can provide similar or even greater physiological, physical and technical responses to more traditional conditioning or training methods. It appears that the intensity at which athletes perform during SSG is dependent on several factors previously described. For example, Hill-Haas et al. (2009c) recommended that coaches aiming to facilitate aerobic-anaerobic conditioning in youth soccer players should use SSG formats with fewer players (e.g. 2 v 2, 3 v 3), as they produce the highest physiological and perceptual responses. This response is further improved when the size of the field is increased (Hill-Haas et al., 2009b; Rampinini et al., 2007). Small-sided games also have the added benefit of incorporating skill-based training and match awareness as players are placed into situations similar to an actual match. Unfortunately, the majority of SSG research has focused on team sports such as soccer and rugby league in which there is generally a greater focus on improvements in physical fitness. Therefore, no research has actually documented the physiological, physical or technical demands associated with
SSG training in other more skill-based sports, and as such it is unclear if this provides a match-intensive training environment.

**Game-Based Training for Cricket**

Cricket is one such sport that imposes considerable physical demands, but typically places a greater emphasis on a player’s technical abilities (Bartlett, 2003; Bartlett, Stockill, Elliott & Burnett, 1996; Stretch, Bartlett & Davids, 2000). As previously mentioned, a SSG approach to cricket training has recently been developed and termed ‘Battlezone’ (Renshaw et al., 2010). The use of BZ requires players to be surrounded by a cricket net placed on the 30 yd inner circle around the pitch and compete under typical match constraints. Unlike CW simulations that are commonly used by cricket coaches, this cricket SSG is performed on modified fields combined with the introduction of new playing rules and scenarios (Renshaw et al., 2010). Typically, CW simulations make use of an entire cricket field, with all players within a cricket team involved and usually played following the same rules as a typical cricket match. The inclusion of the net which surrounds the inner circle of a typical cricket field during BZ, which Renshaw et al. (2010) suggested would re-create match intensity and allow all players to be involved in each delivery. Due to the increased playing size combined with the limited involvement of each player during CW practice, any improvements in the conditioning status or technical demands may be limited. Renshaw et al. (2010) put forward that BZ allows players to acquire cricket-specific skills in a match intensive environment. This may facilitate a greater transference of learnt skills into match-play and thereby creating players with problem-solving abilities (Renshaw et al., 2010). The use of SSG in cricket
is a relatively new concept and therefore, limited information exists detailing the associated physiological and physical responses. Despite previous research suggesting SSG produce similar responses to TCT methods (Dellal et al., 2008; Gabbett, 2006; Hill-Haas et al., 2009a), this information is likely to be specific to each particular sport as the physical demands and intensity levels will be different between sports. To effectively implement BZ in the development of cricket training programs, the physiological and physical demands of cricket players during match-play and current training methods must be understood by both coaching staff and athletes. While research that has quantified the match and training demands of cricket players has increased in the last decade, the use of cricket SSG is not well understood and as such information regarding the physical and physiological demands of this new training method is lacking. At the moment, it remains unknown whether the intensity of BZ compares to traditional forms of cricket training such as CW simulations or net session, or alternatively match-play. Therefore, for coaches looking to implement match-specific training scenarios further research is required on BZ to validate the physical, physiological and technical requirements.

**Conclusion**

As has been detailed, the various cricket playing positions and game formats result in a varied physical and physiological demand (Petersen et al., 2010), which presents a challenge for coaches and athletes alike when developing training programs. Despite the long history of the sport of cricket, as shown through the current review there is a limited understanding of the associated physical and physiological demands during any method of cricket training.
Currently, the majority of cricket training involves typical net sessions more focused on developing technical skill (Pyke & Davis, 2010), in addition to separate conditioning sessions with little time spent developing the ‘game-sense’ or ‘match awareness’ abilities of players. In combination with these traditional training methods, coaches sometimes employ a game-based CW scenario in an effort to try and recreate a match environment. However, no information has detailed the TL's associated with this format. As discussed, the use of SSG within other FBTS provides a match-specific training response encompassing conditioning status, technical skill and ‘game sense’ (Hill-Haas et al., 2011). From the literature presented, it may be plausible to suggest that a similar response could be gained from the use of SSG that has been adapted to cricket (i.e. BZ). As such, for effective and targeted training programs to be developed future research must continue to examine and quantify the physical and physiological responses which occur within cricket players whilst competing and numerous methods of cricket training.
Chapter 3

Study 1

Validity and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis and field-based team sports

As per the peer-reviewed paper Accepted and Published in the Journal of Strength and Conditioning Research:

Abstract

The aim of this study was to determine the accuracy and reliability of 5, 10 and 15 Hz GPS devices. Two male participants (age: 25.5 ± 0.7 yr; height: 1.75 ± 0.01 m; body mass: 74.0 ± 5.7 kg) completed ten repetitions of drills replicating movements typical of tennis, cricket and field-based (football) sports. All movements were completed wearing two 5 Hz and 10 Hz MinimaxX and two GPSports 15 Hz GPS devices in a specially designed harness. Criterion movement data for distance and speed was provided from a 22-camera VICON system sampling at 100 Hz. Accuracy was determined using one-way analysis of variance with Tukey’s post hoc tests. Inter-unit reliability was determined using ICC and typical error was estimated as CV. Overall, for the majority of distance and speed measures from the 5, 10 and 15 Hz GPS devices were not significantly different ($p > 0.05$) to the VICON data. Additionally, no improvements in the accuracy or reliability of GPS devices were observed with an increase in the sampling rate. However, the CV for the 5 and 15 Hz devices for distance and speed measures ranged between 3-33%, with increasing variability evident in higher speed zones. The majority of ICC measures possessed a low level of inter-unit reliability ($r = -0.35–0.39$). Based on these results, practitioners should be aware that measurements of distance and speed may be consistently underestimated, regardless of the movements performed.
Introduction

In the last decade, there has been an increased interest in quantifying the physical demands of training and competition has developed across a range of sports (Duthie, Pyne & Hooper, 2005; Edgecomb & Norton, 2006; Hill-Haas et al., 2010; Petersen et al., 2010). The introduction of GPS devices have allowed the concurrent analysis of movement patterns of numerous players to be completed on a routine basis (Jennings, Cormack, Coutts, Boyd & Aughey, 2010b). Previously, research has attempted to ensure GPS technology is an accurate and reliable tool for measuring movement patterns; however, this often has been limited to straight line and generic movement protocols rather than unstructured movements typical in sport (Barbero-Alvarez, Coutts, Granda, Barbero-Alvarez & Castagna, 2010; Jennings, Cormack, Coutts, Boyd & Aughey, 2010a). As the interpretation of training or match-based GPS data is based on an understanding of the accuracy of the devices used, these previous studies may not provide appropriate understanding of GPS accuracy for unstructured, random movements typical of many team sports.

Originally, GPS technology recorded at 1 Hz, which demonstrated limited accuracy for measuring intermittent, multidirectional and fast movements (Edgecomb & Norton, 2006; Witte & Wilson, 2004). Research has also demonstrated that when sampling at 5 Hz, GPS technology provides an improved and acceptable level of accuracy and reliability for measures of total distance (CV: 2.3-9.8%; ICC: 0.17-0.38) (Coutts & Duffield, 2010; Duffield, Reid, Baker & Spratford, 2010). In contrast, the same 5 Hz GPS devices were reported to possess lower levels of accuracy and reliability (CV: 0.5-39.5%;
ICC: -0.06-0.87) for high-velocity movements or with inclusion of changes of direction typical of court- and field-based team sports when compared to devices of a lower sampling rate over a criterion distance (Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010a). The continued evolution of GPS technology has increased its sampling frequency (10-15 Hz) (Castellano, Casamichana, Calleja-Gonzalez, Roman & Ostojic, 2011). As yet, few studies have reported on the reliability and accuracy of the newer versions of GPS technology, particularly in non-linear sport-specific movement patterns (Castellano et al., 2011).

To date, the majority of data reporting on the quality of GPS technology has focused on the reliability of the systems (Coutts & Duffield, 2010; Edgecomb & Norton, 2006; Jennings et al., 2010a; Petersen, Pyne, Portus & Dawson, 2009a), or have used straight-line drills for criterion distance measures to determine accuracy (Jennings et al., 2010a; Townshend, Worringham & Stewart, 2008). However, only one data set has determined the accuracy of GPS technology for movements typical of sport, particularly unstructured movements that typify training and competition (Duffield et al., 2010). Duffield et al. (2010) reported that in comparison to a high-resolution camera system (VICON system sampling at 100 Hz), both 1 Hz and 5 Hz GPS units underestimated the total distance and speed of specific court-based sport movements. It is therefore possible that the accuracy of GPS technology is limited by its sampling rate. Previous data from Jennings et al. (2010a) demonstrated that the accuracy of measurements was improved for team sport activities with an increase in sampling frequency (from 1 Hz to 5 Hz), regardless
of distance travelled or speed reached. However, these data were limited as they were still collected from straight-line or simple change of direction movements and without a valid criterion measure of distance or speed.

A growing number of studies have used GPS devices to report on the movement patterns of athletes during various match-play and training activities (Cunniffe, Proctor, Baker & Davies, 2009; Gabbett, 2010; Petersen et al., 2010; Wisbey, Montgomery, Pyne & Rattray, 2010). Despite the body of literature on GPS validity (Barbero-Alvarez et al., 2010; Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010a; MacLeod, Morris, Nevill & Sunderland, 2009), there is little similarity between the unstructured, random movement patterns often present in field-based data and the linear and structured movements used in GPS validity studies. Accordingly, a more comprehensive understanding of the accuracy of the GPS devices used for these movement patterns is required, particularly with higher sampling frequency technology (Jennings et al., 2010a). Therefore, the aim of this research was to determine the reliability and accuracy of 5 Hz and 10 Hz MinimaxX as well as 15 Hz SPI GPS systems during straight line running, multi-direction movement patterns, and unstructured movements typical of court- and field-based team sports. It was hypothesized that there would be a reduced accuracy of the GPS technology when compared to VICON. However, it was also hypothesized that both the accuracy and reliability of the GPS technology would be improved with increases in sampling frequency.
Methods

Participants
Two moderately trained males (age: 25.5 ± 0.7 yr; height: 1.75 ± 0.01 m; body mass: 74.0 ± 5.7 kg) participated in the study. Both subjects provided verbal written informed consent (see Appendix A) prior to undertaking the testing session. The Human Research Ethics Committee of the University of Newcastle granted approval for the study (H-2010-1173) (see Appendix B).

Procedure
One subject completed all data collection for drills that replicated movement patterns typical of tennis and cricket, with the second subject completing drills typical of various FBTS. This was to ensure residual fatigue from repeated efforts did not result in slower movement velocities that would not appropriately replicate higher velocities. All testing was performed on a plexicushion outdoor court at the Australian Institute of Sport. During data collection, the subjects wore two 5 Hz (MinimaxX Team Sport v2.5, firmware: v6.59) and two 10 Hz (MinimaxX S4, firmware: v6.72) (MinimaxX, Catapult Innovations, Melbourne, Australia), and two 15 Hz (SPI Pro X, GPSports Systems, Canberra, Australia) GPS devices in a customised harness (see Figure 3.1, over the page).
Figure 3.1: Customised harness used to hold GPS devices.

Each device was housed in a separate pocket across each subject’s back, spaced at least 6 cm apart, with the antenna of each unit exposed to allow a clear satellite reception. All devices were activated 15 min prior to data collection in a clear open area to allow the acquisition of satellite signals. Data collection occurred at night, with an ‘open’ sky present at all times and minimal environmental lighting. Each device ran continuously across the entire testing period. Furthermore, during the testing period, a 22 camera VICON motion analysis system (Oxford Metrics, Oxford, UK) operating at 100 Hz was used to determine criterion movement distance and speed data during each drill. The three-dimensional position of a single reflective marker attached to the centre of the GPS carrying harness was tracked during each drill. Relevant static and
dynamic calibration was undertaken to accurately determine the three-dimensional space in which the simulation drills were completed. The VICON system was calibrated to an accuracy of less than 1 pixel for each camera, with camera resolutions of 12 megapixels, representing an error of 0.0008% (Elliot & Alderson, 2007). For the purpose of analysis, the duration (s) of each drill repetition was calculated from the VICON data and duplicated in the GPS data analysis.

Following the testing session, each device was downloaded to the customised software specific to each GPS model (MinimaxX: Logan Plus 4.6.0, Catapult Innovations, Melbourne, Australia; SPI: Team AMS 5.1, GPS-Sports Systems, Canberra, Australia). Measures of distance as well as mean and peak speeds were calculated post hoc for each respective drill repetition. Measures collated from respective GPS devices were synchronised using GPS time. The duration of each movement was matched to that of the collected VICON data prior to statistical analysis. During post hoc analysis, it was apparent that one 10 Hz MinimaxX unit technically malfunctioned and was therefore removed from analysis. Initially each repetition was identified using the functioning 10 Hz unit and standardised across all other GPS devices. The highest speed value using this method was classified as peak speed, while mean speed was calculated from each repetition of each drill. The accuracy of the remaining 10 Hz unit was calculated and reported.
Movement Protocols

Ten repetitions of each of the 4 respective court-based sports drills and 6 respective field-based sports drills were completed. As outlined above, one participant completed all repetitions of the court-based and cricket-based drills, whilst the second participant completed all FBTS drills.

Court-Based Sports

The court-based sports protocol as reported by Duffield et al. (2010) is shown over the page and was used to replicate the movement demands of tennis and consisted of:

1. a 2 m side-to-side movement pattern from the centre line of the baseline of the tennis court (Figure 3.2a, over the page);

2. a 4 m side-to-side movement pattern from the same position in the previous drill (Figure 3.2b);

3. a run in a rectangle pattern around the lines of the baseline, singles sideline and service line of a standard tennis court (Figure 3.2c), and;

4. a 10 s random movement pattern around the baseline which replicated tennis match-play movements.
Figure 3.2: Schematic representation of the movements used during the court-based protocols (a) 2 m side-to-side; (b) 4 m side-to-side; (c) run around baseline, singles sideline and service line.

Field-Based Sports

Cricket Protocol

1. The batting protocol consisted of a typical run-a-three test (Petersen et al., 2009a). Due to space restrictions the length of the simulated pitch was restricted to 16 m instead of 17.68 m (Figure 3.3a, over the page);

2. The bowling protocol consisted of 15 m straight line run. The 15 m was separated into 5 m of jogging followed by 10 m of high acceleration. The subject then stopped sharply on a marked spot to replicate the start of a bowling delivery (Figure 3.3b), and;

3. The fielding protocol was based upon previously published cricket movement patterns (Petersen et al., 2010). The protocol consisted of three discrete activities:
a. walk 3 m, split step, sprint forward 5 m and then walk back to the start;

b. walk 3 m, split step, sprint right perpendicularly 5 m and then walk back to the start;

c. walk 3 m, split step, sprint backward on right hand side on 45° angle 5 m and then walk back to the start (Figure 3.3c).

Completion of the three fielding directions in succession (forwards, perpendicular, backwards, respectively) counted as one repetition.

Figure 3.3: Schematic representation of the movements used during the cricket protocols (a) run-a-3; (b) bowling; (c) fielding.
**Field-Based Team Sports**

The FBTS protocol (as shown below) was similar to that used in Jennings et al. (2010a) and consisted of:

1. 40 m efforts with seven 90° changes of direction (COD), turning 180° after 20 m and returning to the starting position at sprinting speeds (Figure 3.4a, below);

2. 21 m efforts with seven 45° COD at sprinting speeds (Figure 3.4b), and;

3. Further, a 10 s random movement pattern which replicated FBTS match-play movements (i.e. forward and backward motion, side-stepping and random change in directions).

![Figure 3.4](image)

**Figure 3.4:** Schematic representation of the movements used during the FBTS protocol (a) gradual 5 m COD; (b) tight 3 m COD.
Statistical Analysis

Data is reported as mean ± standard deviation (SD). Data (individual variables within each trial e.g. distance, mean speed, peak speed) that were not within two SD of the mean for each separate movement was considered an outlier and removed prior to data analysis. The difference between each measurement device for distance and speed within each simulation was analysed using a one-way analysis of variance (ANOVA) with Tukey’s post hoc tests ($p < 0.05$). Intra-class correlation were used to assess inter-unit reliability, whilst typical error was expressed as a CV. Statistical analyses were performed using the software package IBM SPSS (version 19, IBM Corporation, Somers, New York, USA) and a customised spreadsheet in Microsoft Excel 2003® (Microsoft, Redmond, USA) (Hopkins, 2009).

Results

GPS Signal Quality

The quality of the signal received by the GPS devices was assessed prior to determining the reliability and accuracy of the devices. A combined horizontal dilution of position (HDOP) for both 5 Hz MinimaxX devices was $1.5 \pm 0.4$ and $1.0 \pm 0.2$ for the 10 Hz device. The HDOP was not reported by the manufacturer software of the 15 Hz GPS devices. The mean number of satellites acquired for the 5 Hz, 10 Hz and 15 Hz GPS devices were $8 \pm 1$, $11 \pm 1$ and $8 \pm 1$, respectively.
Measures of Accuracy

Court-Based Sports

Table 3.1 over the page shows the total distance covered and mean and peak speeds for each device during each court-based movement. During the majority of court-based movements, the distances measured using the GPS devices were not significantly different ($p > 0.05$) to that as measured by VICON. Similarly, the mean and peak speeds from the GPS devices were not significantly different ($p > 0.05$) to VICON. Regardless of sampling rate, no GPS device appeared to report a higher level of accuracy for the distances covered or speeds achieved. To demonstrate, Figure 3.5 (see page 69) shows a representative trace of the measurement of distance and mean speed during a random movement tennis drill. Furthermore, as presented below, the variability in the distance covered and speed reached during court-based movements between devices suggest that no GPS device was more accurate in measuring distance or speed when compared to VICON.
Table 3.1: Measures for distance covered, mean speed and peak speed during court-based sports movements from the movement analysis devices (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>VICON</th>
<th>5 Hz #1</th>
<th>5 Hz #2</th>
<th>10 Hz #1</th>
<th>15 Hz #1</th>
<th>15 Hz #2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2 m Tennis</strong></td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
<td>n=9</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>23.2 ± 1.3</td>
<td>28.2 ± 4.4</td>
<td>21.3 ± 3.1</td>
<td>17.9 ± 2.0</td>
<td>22.1 ± 2.0</td>
<td>19.7 ± 1.8</td>
</tr>
<tr>
<td>Mean Speed (m.s⁻¹)</td>
<td>1.4 ± 0.1</td>
<td>1.3 ± 0.2</td>
<td>1.0 ± 0.2</td>
<td>1.1 ± 0.1</td>
<td>1.4 ± 0.1</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Peak Speed (m.s⁻¹)</td>
<td>2.9 ± 0.4</td>
<td>3.9 ± 0.8</td>
<td>3.3 ± 0.8</td>
<td>2.4 ± 0.2</td>
<td>2.3 ± 0.2</td>
<td>2.3 ± 0.1</td>
</tr>
<tr>
<td><strong>4 m Tennis</strong></td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>45.5 ± 3.8</td>
<td>42.6 ± 5.0</td>
<td>38.2 ± 8.4</td>
<td>36.7 ± 3.6</td>
<td>43.1 ± 4.3</td>
<td>38.3 ± 2.4</td>
</tr>
<tr>
<td>Mean Speed (m.s⁻¹)</td>
<td>2.1 ± 0.1</td>
<td>1.9 ± 0.3</td>
<td>1.6 ± 0.4</td>
<td>1.7 ± 0.1</td>
<td>2.0 ± 0.1</td>
<td>1.8 ± 0.2</td>
</tr>
<tr>
<td>Peak Speed (m.s⁻¹)</td>
<td>3.6 ± 0.2</td>
<td>4.2 ± 0.7</td>
<td>4.7 ± 1.5</td>
<td>3.1 ± 0.1</td>
<td>3.2 ± 0.3</td>
<td>3.9 ± 1.0</td>
</tr>
<tr>
<td><strong>Half Court</strong></td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>25.3 ± 0.8</td>
<td>24.0 ± 4.8</td>
<td>24.3 ± 5.6</td>
<td>21.9 ± 1.6</td>
<td>21.8 ± 1.3</td>
<td>20.9 ± 2.5</td>
</tr>
<tr>
<td>Mean Speed (m.s⁻¹)</td>
<td>3.0 ± 0.4</td>
<td>2.1 ± 0.6</td>
<td>2.1 ± 0.7</td>
<td>2.6 ± 0.3</td>
<td>2.6 ± 0.4</td>
<td>2.5 ± 0.5</td>
</tr>
<tr>
<td>Peak Speed (m.s⁻¹)</td>
<td>4.6 ± 0.5</td>
<td>4.1 ± 1.1</td>
<td>4.3 ± 1.4</td>
<td>4.3 ± 0.2</td>
<td>3.9 ± 0.5</td>
<td>4.1 ± 0.5</td>
</tr>
<tr>
<td><strong>Random Tennis</strong></td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
<td>n=9</td>
<td>n=10</td>
<td>n=10</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>21.6 ± 1.6</td>
<td>25.5 ± 5.4</td>
<td>18.6 ± 2.4</td>
<td>19.0 ± 1.4</td>
<td>19.8 ± 1.5</td>
<td>16.4 ± 2.3</td>
</tr>
<tr>
<td>Mean Speed (m.s⁻¹)</td>
<td>2.1 ± 0.2</td>
<td>1.8 ± 0.3</td>
<td>1.6 ± 0.4</td>
<td>1.8 ± 0.2</td>
<td>1.9 ± 0.2</td>
<td>2.3 ± 0.7</td>
</tr>
<tr>
<td>Peak Speed (m.s⁻¹)</td>
<td>4.7 ± 2.0</td>
<td>4.3 ± 1.0</td>
<td>4.1 ± 0.6</td>
<td>3.3 ± 0.3</td>
<td>3.3 ± 0.3</td>
<td>2.8 ± 0.3</td>
</tr>
</tbody>
</table>

* Within each respective drill type: significantly different to VICON; † Within each respective drill type: significantly different to 5 Hz #1; ‡ Within each respective drill type: significantly different to 5 Hz #2; § Within each respective drill type: significantly different to 10 Hz #1; ¶ Within each respective drill type: significantly different to 15 Hz #1; ″ Within each respective drill type: significantly different to 15 Hz #2.
Figure 3.5: Comparison of speed-time (a) and distance-time (b) curves between VICON and GPS devices for the random tennis protocol.
Field-Based Team Sports

Table 3.2 (over the page) shows the total distance covered and mean and peak speeds for each device during each cricket and FBTS drill. Similar to court simulated movements, the majority of GPS measures were not significantly different ($p > 0.05$) to that of VICON. Similar mean and peak speeds were evident between most GPS devices and VICON ($p > 0.05$). As with the court-based movements, no particular GPS device was of greater accuracy than the others, regardless of sampling frequency. As discussed below, an example of the variability in the distance covered and speeds reached during cricket (fast bowling) and FBTS ($90^\circ$ COD drills) movements are presented below within Figures 3.6 and 3.7 (see pages 72 and 73).
Table 3.2: Comparison of speed-time (a) and distance-time (b) curves between VICON and GPS devices for the random tennis protocol (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>VICON</th>
<th>5 Hz #1</th>
<th>5 Hz #2</th>
<th>10 Hz #1</th>
<th>15 Hz #1</th>
<th>15 Hz #2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Run-a-3</strong></td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>46.7 ± 0.3</td>
<td>46.3 ± 7.6</td>
<td>40.7 ± 8.8</td>
<td>41.1 ± 2.5</td>
<td>40.8 ± 1.9</td>
<td>39.5 ± 8.1</td>
</tr>
<tr>
<td>Mean Speed (m/s)</td>
<td>3.5 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.9 ± 0.7</td>
<td>3.1 ± 0.2</td>
<td>3.1 ± 0.2</td>
<td>3.0 ± 0.6</td>
</tr>
<tr>
<td>Peak Speed (m/s)</td>
<td>6.5 ± 1.3</td>
<td>5.9 ± 0.9</td>
<td>5.4 ± 0.5</td>
<td>5.4 ± 0.3</td>
<td>5.1 ± 0.3</td>
<td>5.0 ± 1.1</td>
</tr>
<tr>
<td><strong>Fast Bowling</strong></td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>15.0 ± 0.2</td>
<td>19.7 ± 4.2</td>
<td>18.0 ± 3.2</td>
<td>13.7 ± 1.4</td>
<td>14.5 ± 0.7</td>
<td>13.5 ± 1.3</td>
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<tr>
<td>Mean Speed (m/s)</td>
<td>3.2 ± 0.1</td>
<td>2.5 ± 0.6</td>
<td>2.5 ± 0.6</td>
<td>2.9 ± 0.4</td>
<td>3.1 ± 0.2</td>
<td>2.8 ± 0.2</td>
</tr>
<tr>
<td>Peak Speed (m/s)</td>
<td>5.9 ± 0.8</td>
<td>4.2 ± 0.9</td>
<td>4.3 ± 1.2</td>
<td>4.9 ± 0.2</td>
<td>5.0 ± 0.3</td>
<td>4.5 ± 0.4</td>
</tr>
<tr>
<td><strong>Fielding</strong></td>
<td>n=8</td>
<td>n=8</td>
<td>n=8</td>
<td>n=8</td>
<td>n=7</td>
<td>n=7</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>39.8 ± 0.4</td>
<td>39.8 ± 0.4</td>
<td>41.2 ± 13.1</td>
<td>35.0 ± 1.5</td>
<td>34.3 ± 1.1</td>
<td>40.3 ± 7.4</td>
</tr>
<tr>
<td>Mean Speed (m/s)</td>
<td>1.5 ± 0.1</td>
<td>1.4 ± 0.4</td>
<td>1.3 ± 0.4</td>
<td>1.3 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>1.5 ± 0.2</td>
</tr>
<tr>
<td>Peak Speed (m/s)</td>
<td>4.1 ± 0.1</td>
<td>4.1 ± 0.1</td>
<td>4.3 ± 0.7</td>
<td>3.9 ± 0.6</td>
<td>3.4 ± 0.2</td>
<td>4.8 ± 1.0</td>
</tr>
<tr>
<td><strong>90º COD</strong></td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
<td>n=9</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>34.7 ± 1.0</td>
<td>34.6 ± 3.7</td>
<td>31.0 ± 6.5</td>
<td>29.2 ± 0.4</td>
<td>29.9 ± 1.81</td>
<td>29.3 ± 1.9</td>
</tr>
<tr>
<td>Mean Speed (m/s)</td>
<td>3.1 ± 0.1</td>
<td>2.4 ± 0.3</td>
<td>2.2 ± 0.5</td>
<td>2.5 ± 0.1</td>
<td>2.7 ± 0.1</td>
<td>2.7 ± 0.3</td>
</tr>
<tr>
<td>Peak Speed (m/s)</td>
<td>4.2 ± 0.1</td>
<td>4.9 ± 1.3</td>
<td>4.9 ± 1.4</td>
<td>3.6 ± 0.1</td>
<td>3.8 ± 0.3</td>
<td>4.3 ± 0.8</td>
</tr>
<tr>
<td><strong>45º COD</strong></td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=9</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>21.2 ± 0.6</td>
<td>22.4 ± 5.6</td>
<td>20.2 ± 3.9</td>
<td>17.9 ± 0.7b</td>
<td>17.1 ± 2.0a</td>
<td>18.6 ± 2.0</td>
</tr>
<tr>
<td>Mean Speed (m/s)</td>
<td>1.8 ± 0.1</td>
<td>1.5 ± 0.3</td>
<td>1.3 ± 0.4</td>
<td>1.5 ± 0.1</td>
<td>1.5 ± 0.2</td>
<td>1.6 ± 0.1</td>
</tr>
<tr>
<td>Peak Speed (m/s)</td>
<td>2.8 ± 0.5</td>
<td>3.2 ± 0.4</td>
<td>3.2 ± 0.9</td>
<td>2.5 ± 0.1</td>
<td>2.4 ± 0.4</td>
<td>3.7 ± 1.0</td>
</tr>
<tr>
<td><strong>Random FBTS</strong></td>
<td>n=10</td>
<td>n=9</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>34.2 ± 4.1</td>
<td>31.9 ± 3.7</td>
<td>33.1 ± 6.5</td>
<td>24.5 ± 3.0a,c</td>
<td>28.4 ± 3.5</td>
<td>29.3 ± 4.8</td>
</tr>
<tr>
<td>Mean Speed (m/s)</td>
<td>2.2 ± 0.3</td>
<td>1.7 ± 0.3</td>
<td>1.8 ± 0.7</td>
<td>1.6 ± 0.2</td>
<td>1.8 ± 0.2</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>Peak Speed (m/s)</td>
<td>4.2 ± 0.5</td>
<td>4.3 ± 0.9</td>
<td>5.0 ± 2.1</td>
<td>3.2 ± 0.4</td>
<td>3.5 ± 0.3</td>
<td>3.7 ± 0.7</td>
</tr>
</tbody>
</table>

* *Within each respective drill type: significantly different to VICON; **Within each respective drill type: significantly different to 5 Hz #1; ***Within each respective drill type: significantly different to 5 Hz #2; ****Within each respective drill type: significantly different to 10 Hz #1; *****Within each respective drill type: significantly different to 15 Hz #1; ******Within each respective drill type: significantly different to 15 Hz #2.
Figure 3.6: Comparison of speed-time (a) and distance-time (b) curves between VICON and GPS devices for the cricket bowling protocol.
Figure 3.7: Comparison of speed-time (a) and distance-time (b) curves between VICON and GPS devices for the COD 90° FBTS protocol.
Measures of Reliability

Table 3.3 (over the page) displays the ICC and CV for the 5 Hz and 15 Hz GPS devices for both court-based, cricket and FBTS drills. Intra-class correlation analysis values for all drills for the 5 and 15 Hz devices ranged from -0.50 to 0.86 and CV ranged between 3 to 33% for each drill for the 5 and 15 Hz devices. Specifically, the ICC values ranged between \( r = -0.41 \) to 0.86 for both devices during the tennis drills, whereas during the cricket and FBTS drills, the ICC values ranged between \( r = -0.50 \) to 0.55 and \( -0.14 \) to 0.73, respectively. The CV for the 5 Hz and 15 Hz devices ranged from 3.5 to 32.9%, 5.5 to 27.1% and 6.2 to 33.4% for the tennis, cricket and FBTS drills, respectively.
Table 3.3: Intra-class correlation analysis (ICC), co-efficient of variation (CV) within movement analysis devices (within models) for each respective drill.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>5 Hz ICC</th>
<th>15 Hz ICC</th>
<th>5 Hz CV (%)</th>
<th>15 Hz CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m Tennis</td>
<td>0.41</td>
<td>0.46</td>
<td>12.0</td>
<td>5.4</td>
</tr>
<tr>
<td>4 m Tennis</td>
<td>0.72</td>
<td>0.10</td>
<td>9.1</td>
<td>8.5</td>
</tr>
<tr>
<td>Half Court</td>
<td>-0.41</td>
<td>0.46</td>
<td>29.0</td>
<td>6.9</td>
</tr>
<tr>
<td>Random Tennis</td>
<td>0.24</td>
<td>0.02</td>
<td>18.4</td>
<td>12.1</td>
</tr>
<tr>
<td>Run-a-3</td>
<td>0.06</td>
<td>-0.17</td>
<td>22.1</td>
<td>17.9</td>
</tr>
<tr>
<td>Fast Bowling</td>
<td>0.06</td>
<td>0.53</td>
<td>21.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Fielding</td>
<td>0.33</td>
<td>-0.16</td>
<td>20.6</td>
<td>17.0</td>
</tr>
<tr>
<td>90° COD</td>
<td>0.41</td>
<td>0.46</td>
<td>17.7</td>
<td>6.2</td>
</tr>
<tr>
<td>45° COD</td>
<td>0.24</td>
<td>0.02</td>
<td>22.7</td>
<td>12.4</td>
</tr>
<tr>
<td>Random FBTS</td>
<td>0.72</td>
<td>0.10</td>
<td>22.8</td>
<td>8.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Speed (m s⁻¹)</th>
<th>5 Hz ICC</th>
<th>15 Hz ICC</th>
<th>5 Hz CV (%)</th>
<th>15 Hz CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m Tennis</td>
<td>-0.14</td>
<td>0.73</td>
<td>19.7</td>
<td>3.5</td>
</tr>
<tr>
<td>4 m Tennis</td>
<td>0.39</td>
<td>0.01</td>
<td>14.9</td>
<td>8.6</td>
</tr>
<tr>
<td>Half Court</td>
<td>0.49</td>
<td>0.86</td>
<td>26.2</td>
<td>7.4</td>
</tr>
<tr>
<td>Random Tennis</td>
<td>-0.02</td>
<td>0.20</td>
<td>21.0</td>
<td>22.8</td>
</tr>
<tr>
<td>Run-a-3</td>
<td>-0.50</td>
<td>-0.10</td>
<td>27.1</td>
<td>16.3</td>
</tr>
<tr>
<td>Fast Bowling</td>
<td>0.50</td>
<td>-0.22</td>
<td>20.2</td>
<td>8.8</td>
</tr>
<tr>
<td>Fielding</td>
<td>0.55</td>
<td>-0.35</td>
<td>21.3</td>
<td>15.2</td>
</tr>
<tr>
<td>90° COD</td>
<td>-0.14</td>
<td>0.73</td>
<td>19.8</td>
<td>7.8</td>
</tr>
<tr>
<td>45° COD</td>
<td>-0.02</td>
<td>0.20</td>
<td>28.1</td>
<td>10.9</td>
</tr>
<tr>
<td>Random FBTS</td>
<td>0.39</td>
<td>0.01</td>
<td>33.4</td>
<td>7.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak Speed (m s⁻¹)</th>
<th>5 Hz ICC</th>
<th>15 Hz ICC</th>
<th>5 Hz CV (%)</th>
<th>15 Hz CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m Tennis</td>
<td>0.03</td>
<td>0.25</td>
<td>22.5</td>
<td>6.4</td>
</tr>
<tr>
<td>4 m Tennis</td>
<td>0.15</td>
<td>-0.08</td>
<td>22.9</td>
<td>20.6</td>
</tr>
<tr>
<td>Half Court</td>
<td>0.05</td>
<td>0.61</td>
<td>32.9</td>
<td>8.2</td>
</tr>
<tr>
<td>Random Tennis</td>
<td>0.13</td>
<td>0.67</td>
<td>20.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Run-a-3</td>
<td>-0.16</td>
<td>0.05</td>
<td>14.2</td>
<td>14.1</td>
</tr>
<tr>
<td>Fast Bowling</td>
<td>0.36</td>
<td>0.03</td>
<td>23.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Fielding</td>
<td>0.49</td>
<td>-0.05</td>
<td>16.2</td>
<td>16.9</td>
</tr>
<tr>
<td>90° COD</td>
<td>0.03</td>
<td>0.25</td>
<td>26.3</td>
<td>14.5</td>
</tr>
<tr>
<td>45° COD</td>
<td>0.13</td>
<td>0.67</td>
<td>20.9</td>
<td>20.0</td>
</tr>
<tr>
<td>Random FBTS</td>
<td>0.15</td>
<td>-0.08</td>
<td>31.5</td>
<td>11.9</td>
</tr>
</tbody>
</table>

Discussion

The purpose of this current research was to determine the accuracy and reliability of GPS devices sampling at various frequencies (5, 10 and 15 Hz) compared to a criterion measure (VICON) during simulated court-based and FBTS movements. The current data demonstrates that increasing the sampling
frequency of GPS technology did not provide any significant improvement in the accuracy of distance and speed measures during simulated court-based and FBTS movements. Past research has reported that GPS devices sampling at a rate of either 1 of 5 Hz underreport distance and speed compared to VICON during court-based movements (Duffield et al., 2010). However, the current data demonstrated that during repetitive and unstructured movements simulating court-based and field-based sports, GPS measures of distance and speed were similar to VICON criterion. Despite this, the current evidence suggests that GPS devices possess an acceptable level of accuracy and reliability when measuring moderate to longer distances whilst running at slow to moderate speeds (Petersen et al., 2009a). However, measures of both reliability and accuracy appear largely reduced when travelling at higher speeds over short distances (Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010a). In agreement, the current study highlights a low to moderate level of reliability of the GPS devices regardless of the sampling rate or the movement performed.

**Total Distance**

The current findings indicate that the total distance measures from the various GPS devices were not significantly different to that of the criterion measure, provided from the VICON camera system. Past comparisons to VICON data has demonstrated that GPS devices consistently reported lower distance values. Duffield et al. (2010) reported that during movements typical of tennis, 1 and 5 Hz GPS devices underreported the distance covered by as much as 38%. Although not significantly different, the results of the current study suggest that GPS devices underreport distance measures that may affect the practical
interpretation of the data. As an example, during the half-court drill, the distance measured using 10 and 15 Hz devices differed to VICON by 13 and 14%, respectively. This is further highlighted within Figure 3.5, which shows total distance was underreported for the majority of GPS devices during each drill presented. When compared to the original work from Duffield et al. (2010), the increase in sampling frequency led to an increase in variability during the same half-court drill when GPS devices were compared to VICON (1 Hz: 17% and 5 Hz: 24%). Previous research has suggested that during short sprints involving high accelerations, GPS systems possess reduced accuracy compared to longer sprints or slower speeds, which may account for this overestimation (Jennings et al., 2010a). The present results also highlight that during unstructured movements typical of match-play, all three models of GPS devices underreported the total distance covered (10-28%) when compared to VICON during random, unstructured court-based and FBTS drills. Therefore, practitioners using GPS devices should be aware of the resultant underreporting of measures of external load (i.e. total distance) during unstructured movements in field-based scenarios, and that this may not be altered due to increased sampling rates, as has been previously suggested (Duffield et al., 2010).

Mean and Peak Speed
As reported for total distance, similar outcomes for mean and peak speed were evident from GPS devices compared to VICON. However, there was evidence suggesting that the GPS devices only slightly underreported measures of mean and peak speed. These results are similar to that of previous research (Duffield
et al., 2010), whereby mean and peak speed measurements taken during sport-specific movements using GPS technology were consistently lower than that of the criterion VICON measure. As previously highlighted in Figures 3.5-3.7, GPS technology underestimated the mean and peak speeds during unstructured movements typical of court-based and FBTS when compared to VICON, regardless of the sampling rate. Hence, regardless of the sport or sampling frequency, practitioners should note that regular non-linear motions, typical of most sports are likely to increase GPS error. Further, as with total distance covered, GPS devices slightly underreported in comparison to VICON, despite not being statistically significant for both mean (13-29% difference) and peak speeds (14-29% difference) depending on the drill performed. As such, the use of GPS devices to measure speed during sport-specific movements was not significantly different to the criterion measure. However, it should be still interpreted with caution in field-based settings given the underreporting observed in this and in earlier research (Duffield et al., 2010).

**Reliability of GPS Devices**

When compared to the 5 Hz devices, the inter-unit CV for the distance covered and mean and peak speed were lower in devices with a higher sampling rate. In the current data, the higher CV in the 5 Hz units may be explained by the lower sampling frequency which led to fewer data points being captured by the lower frequency devices (refer to Figures 3.5-3.7), possibly resulting in a higher proportion of movement not being reported in the lower sensitivity devices. The reported inter-unit CV for the measures included in the present data also differed to previously published data for similar movements (Duffield et al.,
Regardless of the shorter distance used in the current study and a higher sampling rate, Petersen et al. (2009a) reported a smaller measure of error when performing the run-a-3 drill using either 1 or 5 Hz GPS devices. Similar discrepancies can be observed between the 5 and 15 Hz devices in the current study, as a greater inter-unit CV was evident during the 90º COD (gradual) and 45º COD (tight) compared to the data published by Jennings et al. (2010a) (gradual COD: 1 Hz: 10.7%; 5 Hz: 7.9%; tight COD: 1 Hz: 12.0%; 5 Hz: 9.2%). Similar to the court-based drills, the CV was higher when performing the FBTS movements within the 15 Hz devices. However, this trend was not repeated upon observation of the inter-unit reliability with a greater ICC being reported for almost half of the distance and speed measures for the 5 Hz devices during the FBTS drills. In particular, total distance as well as mean and peak speeds during the fielding drill were greater when using the lower frequency devices. Importantly, very few measures displayed an ICC value that could be classified as moderately reliable, regardless of sampling frequency. This finding lends itself to the previous finding that the inter-unit reliability of GPS devices may be poor for movements associated with FBTS (Coutts & Duffield, 2010).

Previous research has demonstrated that the accuracy of GPS is influenced by the nature of the movements performed (Duffield et al., 2010; Jennings et al., 2010a). In particular, Duffield et al. (2010) reported that the mean and peak speed of movements similar to those performed during a typical tennis match were underestimated by the 1 and 5 Hz GPS devices. The current study made similar observations not only during court-based movements, but also those
typical of FBTS. The results of this study show the accuracy of the GPS technology for distance and speed measures was not improved with an increase in sampling rate regardless of the movements performed, which is in contrast to the findings of previous research (Duffield et al., 2010; Jennings et al., 2010a). It was hypothesized that a greater resolution would result in improved accuracy for determining distance and speed measures, especially during movements such as the 45° COD and the fielding drills. Based on previous suggestions from (Duffield et al., 2010; Jennings et al., 2010a) it was assumed that this improvement would be due to an increased number of data points captured with the increase in GPS sampling frequency. However, the results of the current study do not support this hypothesis.

It should be noted that these reported findings of the study might be subject to several limitations. Firstly, the quality of the GPS signal may have influenced the data quality. Importantly, HDOP is the main quality indicator of the GPS signal quality, and values >1 may indicate a poor quality signal. As such, the mean HDOP in the current study were 1.5 ± 0.4 and 1.0 ± 0.2 for the 5 and 10 Hz devices, respectively. However, these figures are similar to that reported in previous studies (Duffield et al., 2010; Jennings et al., 2010a) where increases in the sampling rate improved GPS reliability. Of particular interest, the 10 Hz unit in the current study acquired a greater number of satellites than either the 5 and 15 Hz devices. Based on this evidence it is unlikely that any unexpected results in this investigation were due to a poor HDOP or too few a number of acquired satellites. Data quality may also have been compromised by the placement of the devices within the custom harness; however it would be
surprising if the quality of the GPS data were compromised with no changes in the highlighted quality indicators. However, the customised harnesses worn in the current study is common practice within GPS reliability and accuracy studies (Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010a; Petersen et al., 2009a).

**Conclusion**

The current data demonstrated that GPS devices provided statistically similar distance and speed measures when compared to a criterion measure (VICON). However, in agreement with previous research (Duffield et al., 2010), there was a tendency for the GPS devices to underestimate these measures during straight line running, multi-direction movement patterns, and unstructured movements typical of team sports. Further, the distance and speed measures of the GPS devices demonstrated a low to moderate level of inter-unit reliability when performing high-speed straight line running, multi-direction movement patterns, and unstructured movements (Coutts & Duffield, 2010; Duthie et al., 2005; Jennings et al., 2010a). However, unlike previous research (Duffield et al., 2010; Jennings et al., 2010a; Portas, Harley, Barnes & Rush, 2010), no improvements in either accuracy or reliability were evident with increases in GPS sampling frequency.

Based on this evidence, it is recommended that practitioners understand the limitations that may arise when using GPS devices for interpretation of TL monitoring during match-play and training. In particular, the low accuracy and
reliability of HI efforts is of concern given the proposed importance of such measures to training and performance outcomes. Currently GPS analysis remains the most effective and time-efficient for monitoring workload within the team sport environment. By applying the information of the current study, practitioners should interpret differences in matches or training session based on the accuracy and variability reported here. As others have stated, it would be recommended that subjects wear the same device during training or data collection sessions. Finally, practitioners should be aware that these results are specific to the hardware and software of the units used in this study and may not be applicable to other versions or devices.

**Practical Applications**

- GPS devices provide a consistent analysis of sport-specific movements, such as straight line running, multi-direction movement patterns, and unstructured movements.
- Coaches should be aware that regardless of sampling frequency, GPS devices tend to underestimate the distance covered and speeds reached during sport-specific movements. This must be factored into the development of training programs based on information gathered from GPS devices.
- To avoid any inter-unit error, players should wear the same GPS device whilst training or competing where possible.
Chapter 4
Study 2

Comparison of the physiological, physical and technical demands of cricket players during traditional net-based training, centre-wicket simulation and One-Day cricket matches.

As per the peer-reviewed paper Under Review in the Journal of Strength and Conditioning Research:

Abstract

Currently, little information exists pertaining to the TL’s experienced by cricket players during training sessions and competitive matches. This study compared the physiological, physical and technical demands of elite cricket players during TCT, CW simulations and OD matches. The HR, RPE and movement patterns of 42 cricket players (age: 23 ± 4 yr, height: 1.86 ± 0.07 m, body mass: 85.8 ± 8.5 kg) were measured across the three separate cricket-specific exercises. Video analysis was retrospectively coded to quantify the technical loads. The data demonstrated similar global physiological (HR_{mean}: 148 ± 16 b\,min^{-1}; 148 ± 9 b\,min^{-1}) and physical (mean speed: 82 ± 13 m\,min^{-1}; 77 ± 28 m\,min^{-1}) demands between TCT and OD matches for medium-fast bowlers, respectively. Within all other playing positions, greater physiological and physical demands were demonstrated to result from OD matches compared to either training format. Regardless of playing position, the technical demand appeared greatest during TCT compared to the other formats. While the data demonstrated that TCT provided players with a physically and technically demanding training environment, the lack of match condition replication remains of concern. Interestingly, the CW simulations were insufficient to replicate the physical, physiological or technical loads of match-play. Therefore, while TCT provided a specific training stimulus similar to match-play, CW simulations failed to replicate match-intensity and provided an inadequate training stimulus across all playing positions.
Introduction

In preparing training programs, coaches must consider the principle of specificity that the demands and movements patterns experienced during training should closely replicate that of match-play to gain maximal adaptation (Reilly et al., 2009). Additionally, this principle must also be applied to the technical skills performed by the athletes to allow for improvements in technical performance whilst performing match-specific movements. As such, coaches must develop effective skill-oriented training sessions, whilst maintaining appropriate physical conditioning. Within FBTS (e.g. Australian football, soccer, and rugby league) the use of match-specific training activities have proven to replicate the physiological responses and physical demands of typical match-play (Dawson, Hopkinson, Appleby, Stewart & Roberts, 2004; Kelly, Gregson, Reilly & Drust, 2013). Unfortunately, limited data exists examining the demands associated with match-specific training activities within more skill-oriented sports such as cricket.

Previously, the majority of training sessions within high-performance cricket environments have encompassed net-based activities that are combined with fielding-specific drills, often held separately to conditioning based training exercises (Pyke & Davis, 2010). Petersen et al. (2011a) recently reported that skills sessions designed to practice isolated aspects of a player’s ability were performed at a lower physical and physiological intensity than a competitive cricket match-play (Petersen et al., 2010). Similarly, CW (game-based) simulations present a popular pre-competition training tool that is implemented to replicate match demands, though such training is also reported to be
performed at lower intensities than competitive match-play (Petersen et al., 2011a). Whilst this previous research has reported on the physical stimuli of respective training modes, cricket training is often focused on the development of skill-specific ability, especially given the high technical demands of the game. However, the technical demands in conjunction with the physical loads of the respective training scenarios remain to be reported. Accordingly, the aim of this study was to quantify and compare the physiological, physical and technical demands of cricket players within respective playing positions, during TCT sessions, CW simulations and competitive OD matches.

Methods

Participants
A total of 42 male, cricket players (age: 23 ± 4 yr, height: 1.86 ± 0.07 m, body mass: 85.8 ± 8.5 kg) from Cricket Australia’s National Cricket Centre (which included players from the Under 19s World Cup squad and current state cricket players) participated in separate CW simulations (n = 5), traditional net-based training (n = 14) and OD cricket matches (n = 5). Participants were professional cricket players who performed a minimum of three cricket-specific training sessions per week, in addition to a minimum of three strength and conditioning sessions. Participants were classified as either a batsman, medium-fast bowler, spin bowler, fielder or wicketkeeper according to their specific role throughout the training session. Each player provided verbal and written informed consent (see Appendix C) after the study was approved by the University of Newcastle Human Research Ethics Committee (H-2010-1288) (see Appendix D).
Procedures

Prior to each training session and match, participants completed a standardised 15 min warm-up that comprised of LI running, dynamic stretches and cricket skill-based exercises as led by coaching staff. During CW simulations, participants practised technical skill under match-like conditions on a typical cricket field with the training environment (e.g. field dimensions, playing rules) and were performed under normal cricket rules and regulations (International Cricket Council, 2009) unless stated otherwise by the coaching staff. The duration of each CW simulation was categorised into playing position: batsmen (n = 25): 33 ± 17 min; medium-fast bowlers (n = 17): 77 ± 35 min; spin-bowlers (n = 9): 81 ± 48 min; fielders (n = 13): 43 ± 35 min, and; wicketkeepers (n = 4): 78 ± 35 min.

The TCT sessions were comprised of both net-based and fielding sessions. The net-based sessions required batsmen to continuously bat whilst a maximum of three bowlers per net bowled continuously during the session. All players were instructed to bat and bowl as they would during a typical cricket match. During the sessions the bowlers were separated into specific nets dependent on whether they were a medium-fast or spin bowler. Batsmen swapped between the different nets during a session to ensure they batted against both types of bowling. The average duration of the batting session (n = 62) was 32 ± 10 min. Each bowler was restricted to bowling a maximum number of balls each session which was determined before each session by the medical staff. The average duration of a medium-fast (n = 101), and; spin (n = 19) bowling session was 38 ± 12 min and 35 ± 9 min, respectively. The fielding sessions (n = 35) were
completed separately to the net-based sessions and lasted 60 ± 16 min. During the fielding sessions, participants were involved in a range of group and individual drills designed to train all aspects of cricket fielding including catching, throwing and ground fielding. Those involved in wicketkeeping completed a further separate training session that focused on skills such as catching and correct movement patterns. The average duration of a specific wicketkeeping session (n = 8) was 45 ± 23 min.

Data collected during both the CW simulation and the TCT sessions were compared to 50-over OD cricket matches played by the Australian Under 19s World Cup squad. Participants performed as they would normally during any competitive OD match and were restricted by the rules and regulations outlined by the International Cricket Council (2009). The duration of each match was categorised by playing position: batsmen (n = 11): 47 ± 45 min; medium-fast bowlers (n = 9): 148 ± 43 min; spin-bowlers (n = 8): 172 ± 36 min; fielders (n = 10): 149 ± 43 min, and; wicketkeepers (n = 4): 155 ± 49 min.

**Physiological Measures**

A Polar Team² System (Polar Electro Oy, Kempele, Finland) measured HR at 5 s intervals throughout each training session and match. Each individual’s HR\textsubscript{max} was determined based on the HR achieved prior to exhaustion from the performance of a Yo-Yo Intermittent Recovery Test (Level 1) completed prior to the commencement of the testing sessions. Five HR zones were used to classify intensity, consisting of: Zone 1 (0-50% HR\textsubscript{max}), Zone 2 (51-75% HR\textsubscript{max}), Zone 3 (76-85% HR\textsubscript{max}), Zone 4 (86-95% HR\textsubscript{max}) and Zone 5 (>95% HR\textsubscript{max}).
The time spent (absolute and percentage of total time) within each of the HR zones during each training session and match was calculated using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia).

Thirty minutes following each CW simulation and TCT session, and upon the completion of each innings of each match; each participant provided a RPE using the category-ratio 10 (CR-10) RPE scale (Borg, Hassmen & Lagerström, 1987). Training load was then calculated by multiplying each player’s RPE by the duration (min) of each training session or match (Foster et al., 1995).

**Time-Motion Characteristics**

The movement patterns of each participant during all training sessions and matches were recorded via MinimaxX GPS devices (v6.65, Catapult Innovations, Melbourne, Australia) that sampled at a frequency of 10 Hz. Each GPS device was situated between the shoulder blades of each participant using the manufacturers harness. The GPS units were turned on 15 min prior to participant’s entering the playing area to ensure a satellite lock was established. As per Petersen et al. (2010), the following speed zones were used for a data analysis: standing/walking (0-2.00 m·s\(^{-1}\)), jogging (2.01-3.50 m·s\(^{-1}\)), running (3.51-4.00 m·s\(^{-1}\)), striding (4.01-5.00 m·s\(^{-1}\)) and sprinting (>5.01 m·s\(^{-1}\)). Further to this, work-to-recovery ratio was defined as the ratio of time spent completing HI (running, striding, sprinting) to LI (standing/walking, jogging) activity (Petersen et al., 2010). Data was downloaded to determine movement characteristics of each participant following each session and match using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia). The movement data was
then made relative to each hour of training or competition to standardise between sessions of different durations (Petersen et al., 2010). To ensure consistency between training sessions and match-play, the starting point of each bout was classified as the initial increase in velocity of the first delivery of the session. Each session was completed following the final delivery/dismissal using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia).

**Technical Skills**

Each CW simulation and TCT session was filmed using two fixed video cameras (HDR-JP10E, Digital HD Video Camera Recorder, Sony, Japan) that were time aligned for analysis by synchronising the initial balled bowled during each testing session. During the net-based sessions, one was positioned on the cricket pitch behind the stumps at the opposite end to which each ball was delivered. During fielding training sessions, a single camera was positioned so that all players were in view of the camera. During CW simulations and match-play, one camera was placed level with midpoint of the pitch and perpendicular to the pitch outside the playing area, with a second camera placed directly behind the pitch, above the sightscreen.

The video was retrospectively analysed after each training session and match to examine the technical characteristics of each playing position. Specifically, the number of deliveries faced and hit by batsmen were tallied, along with the number of times dismissed and chances provided. During CW and OD matches, chances were defined as a missed opportunity for dismissing a batsman by an opposing player. This was either a dropped catch or a missed
stumping/run-out. As no fielders were present during the TCT sessions, only dropped catches from bowlers (with no assistance from the surrounding nets) and edges hit directly behind the batsmen were considered a chance. Batting performance was assessed by classifying bat-ball contact as “good”, “bad” or “no” contact, with “no” being separated into “dot balls” and “play/miss” (Houghton et al., 2011a; Muller & Abernethy, 2008). The number of balls bowled by medium-fast and spin bowlers was also recorded. Further to this, the number of throws completed by each player when fielding was counted.

**Statistical Analysis**

All data were reported as mean ± SD. Any data recorded whilst a player was not directly involved in a training session or match was not included in analyses. Data recorded during breaks in play during a match (e.g. drinks break) were removed for analysis. Using a customised spreadsheet developed by Hopkins (2003) effect sizes (Cohen’s d) (Cohen, 1988) (small = 0.2-0.49, moderate = 0.5-0.79, large = ≥0.8) were used to quantify the magnitude of difference of the physiological, physical and technical measures within each playing format between the different formats.

**Results**

**Batsmen**

As shown in Table 4.1 (see page 93), the greatest %HR$_{\text{max}}$ and HR$_{\text{mean}}$ occurred during OD matches, when compared to TCT (d = 1.14 and 1.11) and CW simulations (d = 0.46 and 0.48), respectively. This was combined with less time spent below 75%HR$_{\text{max}}$ during OD matches and greater time above
85\%HR_{max} than TCT (d = 0.63 and 0.85) and CW simulations (d = 0.21 and 0.37), respectively. The RPE following OD matches demonstrated a moderate effect to be higher following a batting innings compared to TCT (d = 0.53) and CW simulations (d = 0.78). From this, the increased TL of batsmen during OD matches resulted in a small (d = 0.30) and moderate (d = 0.71) effect following the respective net and CW training formats.
Table 4.1: Comparison of the physiological responses by playing position during traditional cricket training, centre-wicket simulation and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Physiological and Perceptual Responses</th>
<th>Batsman</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCT</td>
<td>CW</td>
<td>OD</td>
<td>TCT</td>
<td>CW</td>
</tr>
<tr>
<td>Peak %HRmax</td>
<td>88 ± 11</td>
<td>96 ± 7§</td>
<td>100 ± 10†</td>
<td>96 ± 16</td>
<td>100 ± 10†</td>
</tr>
<tr>
<td>HRmean (b min⁻¹)</td>
<td>137 ± 14</td>
<td>146 ± 12¿</td>
<td>152 ± 13¿</td>
<td>148 ± 16</td>
<td>129 ± 17¾</td>
</tr>
<tr>
<td>HR Zones (% of Time)</td>
<td>1</td>
<td>5 ± 11</td>
<td>0 ± 10↓</td>
<td>8 ± 16</td>
<td>13 ± 14↑</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>61 ± 31</td>
<td>52 ± 27↑</td>
<td>41 ± 32↓</td>
<td>38 ± 28</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>28 ± 27</td>
<td>36 ± 20↑</td>
<td>25 ± 14↓</td>
<td>33 ± 19</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4 ± 7</td>
<td>12 ± 11</td>
<td>15 ± 17↑</td>
<td>18 ± 20</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1 ± 2</td>
<td>1 ± 1</td>
<td>4 ± 5∆</td>
<td>3 ± 7</td>
</tr>
<tr>
<td>RPE (AU)</td>
<td>2.9 ± 1.0</td>
<td>2.7 ± 0.9</td>
<td>3.4 ± 0.9</td>
<td>4.7 ± 1.1</td>
<td>4.5 ± 1.5</td>
</tr>
<tr>
<td>TL (AU hr⁻¹)</td>
<td>182 ± 78</td>
<td>163 ± 55</td>
<td>202 ± 55†</td>
<td>301 ± 360</td>
<td>293 ± 360↑</td>
</tr>
</tbody>
</table>

Difference in comparison to TCT (| small; * moderate; ^ large); Difference in comparison to CW simulation (| small; * moderate; ^ large).
Table 4.2 (over the page) displays the physical demands of the various cricket positions across each training or match format. There were large effects for less distance to be covered per hour during the TCT sessions than either CW simulations ($d = 2.33$) or OD matches ($d = 0.89$). The same effect was also shown in the relative distance covered at a HI during TCT ($d = 3.60$ and $1.15$, CW simulations and OD matches, respectively). A large effect also existed for mean speed to be lower during the TCT sessions than CW simulations ($d = 2.35$) and OD matches ($d = 0.90$). Only small to moderate effects were reported for a greater total relative distance, relative distance at a HI and mean speed during OD matches ($d = 0.49$, 0.33 and 0.50, respectively) when compared to the CW simulations. There was a small to moderate effect for a greater number of HI activities ($d = 0.41$) and sprints ($d = 0.21$), combined with a longer work-to-recovery ratio ($d = 0.29$) that characterised OD matches rather than CW simulations (Table 4.3, page 96). Overall, there was an increase in the movement characteristics during CW simulations ($d = 4.17 \pm 4.10$) and OD matches ($d = 1.63 \pm 0.63$) compared to traditional net sessions. The greatest technical demands for batsmen occurred during the TCT (Table 4.4, page 98), with a large effect for a greater number of technical measures performed reported compared to CW simulations ($d = 1.24 \pm 0.67$) and OD matches ($d = 1.13 \pm 0.49$). In particular, the number of balls faced and balls hit during OD matches ($d = 0.43 \pm 0.24$) where higher than that of CW simulations.
Table 4.2: Distance covered in each movement category across playing positions during traditional cricket training, centre-wicket simulation and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Measures of Movement</th>
<th>Batsman</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCT (n=62)</td>
<td>CW (n=25)</td>
<td>OD (n=11)</td>
<td>TCT (n=101)</td>
<td>CW (n=17)</td>
</tr>
<tr>
<td><strong>Distance Covered</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m·hr⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jogging</td>
<td>122 ± 47 ± 239</td>
<td>179 ± 42 ± 115 ± 239</td>
<td>113 ± 84 ± 144</td>
<td>61 ± 158 ± 105</td>
<td>112</td>
</tr>
<tr>
<td>Striding</td>
<td>247 ± 94 ± 304</td>
<td>411 ± 227 ± 313</td>
<td>3 ± 9</td>
<td>69 ± 48</td>
<td>174</td>
</tr>
<tr>
<td>Sprinting</td>
<td>8</td>
<td>155 ± 38 ± 56</td>
<td>1003 ± 429 ± 427</td>
<td>0</td>
<td>58</td>
</tr>
<tr>
<td><strong>Total Distance</strong></td>
<td>1512 ± 2284 ± 3230 ± 788 ± 795 ± 1743</td>
<td>4931 ± 3854 ± 4653</td>
<td>2975 ± 3075 ± 3486</td>
<td>2980 ± 2544 ± 3822</td>
<td>2980 ± 2544 ± 3822</td>
</tr>
<tr>
<td>Low-Intensity</td>
<td>1471 ± 1720 ± 2446</td>
<td>3315 ± 3068 ± 3733</td>
<td>2904 ± 2801 ± 2974</td>
<td>2572 ± 2319 ± 3235</td>
<td>2572 ± 2319 ± 3235</td>
</tr>
<tr>
<td>Distance</td>
<td>338 ± 151 ± 1820 ± 521</td>
<td>524 ± 1152</td>
<td>589</td>
<td>654</td>
<td>834</td>
</tr>
<tr>
<td>High-Intensity</td>
<td>36 ± 71</td>
<td>555 ± 191</td>
<td>772 ± 905</td>
<td>1573 ± 771 ± 977</td>
<td>64 ± 163</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>792 ± 1278 ± 3734</td>
<td>3060 ± 4695 ± 10830</td>
<td>1674 ± 3813 ± 10065</td>
<td>239 ± 2001</td>
<td>4207</td>
</tr>
<tr>
<td>Mean Speed (m·min⁻¹)</td>
<td>25 ± 6</td>
<td>38 ± 5 ± 45</td>
<td>82 ± 13</td>
<td>64 ± 13</td>
<td>77 ± 28</td>
</tr>
</tbody>
</table>

Difference in comparison to TCT († small; ‡ moderate; † large); Difference in comparison to CW simulation († small; ‡ moderate; † large).
Table 4.3: Movement characteristics by playing position during traditional cricket training, centre-wicket simulation and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Movement Characteristics</th>
<th>Batsman</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCT (n=62)</td>
<td>CW (n=25)</td>
<td>OD (n=11)</td>
<td>TCT (n=101)</td>
<td>CW (n=17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OD (n=9)</td>
</tr>
<tr>
<td>High-Intensity Efforts (#hr⁻¹)</td>
<td>11 ± 17</td>
<td>59 ± 41§</td>
<td>132 ± 250‖</td>
<td>183 ± 40</td>
<td>88 ± 37§</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>114 ± 46‖</td>
</tr>
<tr>
<td>Sprints (#hr⁻¹)</td>
<td>1 ± 3</td>
<td>23 ± 9§</td>
<td>26 ± 18‖</td>
<td>58 ± 13</td>
<td>25 ± 15§</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26 ± 10§</td>
</tr>
<tr>
<td>Mean Sprint Distance (m)</td>
<td>0</td>
<td>8 ± 1§</td>
<td>14 ± 9§Δ</td>
<td>17 ± 5</td>
<td>16 ± 5†</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16 ± 5†</td>
</tr>
<tr>
<td>Maximal Speed (m.s⁻¹)</td>
<td>3.3 ± 1.1</td>
<td>6.0 ± 0.4</td>
<td>7.9 ± 3.1§Δ</td>
<td>6.6 ± 1.3</td>
<td>6.9 ± 1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.5 ± 1.1</td>
</tr>
<tr>
<td>Work-to-Recovery Ratio (1:x)</td>
<td>487 ± 445</td>
<td>33 ± 15§</td>
<td>41 ± 36§</td>
<td>11 ± 3</td>
<td>28 ± 15§</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19 ± 6§</td>
</tr>
</tbody>
</table>

Difference in comparison to TCT († small; ‡ moderate; § large); Difference in comparison to CW simulation (‖ small; ¶ moderate; ‖ large).
Medium-Fast Bowlers

A small effect was reported for a lower peak $\%HR_{\text{max}}$ during TCT than CW simulation ($d = 0.30$) and OD matches ($d = 0.32$). A large effect existed for a greater $HR_{\text{mean}}$ during TCT ($d = 1.15$) and OD matches ($d = 1.40$) than CW simulations. As shown in Table 4.1, the percentage of time spent within each respective HR Zone varied between the different training formats and OD matches. A greater RPE was reported following OD matches when compared to either TCT ($d = 1.33$) and CW simulations ($d = 1.26$). Traditional cricket training demonstrated a small ($d = 0.32$) and moderate ($d = 0.57$) effect for a lower TL compared to CW simulations and OD matches, respectively.

The greatest relative distance was covered during TCT as shown in Table 4.2 when compared to either CW simulations ($d = 1.36$) or OD matches ($d = 0.21$). The relative distance covered at HI was also greatest during, when compared to either CW simulations ($d = 2.12$) or OD matches ($d = 1.31$). Small ($d = 0.47$) and moderate ($d = 0.74$) effects existed for a greater distance covered at LI during OD matches than TCT and CW simulations, respectively. Mean speed was greatest during TCT with a small effect compared to OD matches ($d = 0.23$) and large effect compared to CW simulations ($d = 1.38$). There was a large effect for a greater number of HI activities and sprints to be performed during TCT than CW simulations ($d = 2.47$ and 2.35) and OD matches ($d = 1.60$ and 2.76), respectively. A lower work-to-rest ratio resulted from TCT (Table 4.3), with larger effect for less recovery time between HI efforts compared to CW ($d = 1.57$) and OD matches ($d = 1.69$). A greater total number of balls were bowled during OD matches (Table 4.5) than during either TCT ($d = 0.84$) or CW
simulations ($d = 2.39$). However, a greater number of balls were bowled per hour in TCT than either CW simulations ($d = 2.81$) and OD matches ($d = 3.81$).

**Table 4.4:** Technical characteristics of elite batsmen during traditional cricket training, centre-wicket simulation and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Technical Characteristics</th>
<th>TCT ($n=62$)</th>
<th>CW ($n=25$)</th>
<th>OD ($n=11$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balls Faced ($# hr^{-1}$)</td>
<td>99 ± 37</td>
<td>44 ± 17$^§$</td>
<td>51 ± 15$^§</td>
</tr>
<tr>
<td>Balls Hit ($# hr^{-1}$)</td>
<td>81 ± 33</td>
<td>30 ± 9$^§$</td>
<td>39 ± 13$^§</td>
</tr>
<tr>
<td>Dot Balls ($# hr^{-1}$)</td>
<td>45 ± 15</td>
<td>23 ± 18$^§$</td>
<td>28 ± 12$^§</td>
</tr>
<tr>
<td>Play-Miss ($# hr^{-1}$)</td>
<td>9 ± 4</td>
<td>5 ± 4$^§$</td>
<td>6 ± 4$^§</td>
</tr>
<tr>
<td>Defensive Shots ($# hr^{-1}$)</td>
<td>29 ± 13</td>
<td>9 ± 8$^§$</td>
<td>13 ± 7$^§$</td>
</tr>
<tr>
<td>Attacking Shots ($# hr^{-1}$)</td>
<td>51 ± 26</td>
<td>20 ± 12$^§$</td>
<td>26 ± 11$^§$</td>
</tr>
<tr>
<td>Times Dismissed ($# hr^{-1}$)</td>
<td>1 ± 1</td>
<td>2 ± 4$^†$</td>
<td>2 ± 2$^§$</td>
</tr>
<tr>
<td>Chances ($# hr^{-1}$)</td>
<td>3 ± 3</td>
<td>2 ± 4$^†$</td>
<td>1 ± 1$^§</td>
</tr>
<tr>
<td>% Good Contact Shots</td>
<td>80 ± 8</td>
<td>72 ± 11$^§$</td>
<td>77 ± 9$^†$</td>
</tr>
</tbody>
</table>

*Difference in comparison to TCT († small; * moderate; § large); Difference in comparison to CW simulation († small; * moderate; § large).*
Table 4.5: Technical characteristics of elite medium-fast bowlers, spin bowlers, fielders and wicketkeepers during traditional cricket training, centre-wicket simulation and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Technical Characteristics</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCT (n=101)</td>
<td>CW (n=17)</td>
<td>OD (n=9)</td>
<td>TCT (n=19)</td>
</tr>
<tr>
<td>Total Balls Bowled (#)</td>
<td>38 ± 12</td>
<td>24 ± 5§</td>
<td>49 ± 14§</td>
<td>59 ± 11</td>
</tr>
<tr>
<td>Balls Bowled (#/hr⁻¹)</td>
<td>62 ± 14</td>
<td>24 ± 13§</td>
<td>21 ± 6§</td>
<td>102 ± 23</td>
</tr>
<tr>
<td>Total Throws (#)</td>
<td>3 ± 4</td>
<td>9 ± 4 Δ</td>
<td>3 ± 3</td>
<td>11 ± 7 Δ</td>
</tr>
<tr>
<td>Throws (#/hr⁻¹)</td>
<td>2 ± 2</td>
<td>4 ± 1 Δ</td>
<td>4 ± 3</td>
<td>4 ± 2</td>
</tr>
</tbody>
</table>

Difference in comparison to TCT († small; § moderate; ‡ large); Difference in comparison to CW simulation († small; § moderate; ‡ large).
Spin Bowlers

A large effect existed for peak %HR$_{\text{max}}$ to be lower during TCT than CW simulation ($d = 1.33$) and OD matches ($d = 0.88$). A similar HR$_{\text{mean}}$ was maintained during TCT and CW simulations with a small effect present compared to OD matches ($d = 0.31$ and 0.25, respectively). The training formats and matches varied the percentage of time spent within each HR Zone as shown in Table 4.1. The greatest measures of RPE and TL occurred following OD matches in comparison to TCT ($d = 1.84$ and $3.83$) and CW simulations ($d = 0.97$ and $0.84$), respectively.

Greater relative distance was covered in both TCT ($d = 0.52$) and CW simulations ($d = 0.40$) than during OD match-play. A similar LI relative distance was covered during each respective format, with a greater HI relative distance covered during CW simulations and OD matches than TCT ($d = 1.30$ and $1.37$, respectively) (Table 4.2). As shown in Table 4.3, large effects existed for all movement characteristics measured when compared to CW simulations ($d = 2.08 \pm 1.97$) and OD matches ($d = 2.88 \pm 3.09$) compared to TCT. A longer work-to-rest ratio was observed during TCT than CW simulations ($d = 1.66$) and OD matches ($d = 1.72$). A greater number of balls were bowled during TCT in both overall and relative to duration terms than centre-wicket simulations ($d = 3.85$ and $3.11$, respectively). When compared to OD matches these same measures showed a moderate ($d = 0.80$) and large ($d = 4.94$) effect.
Fielders

As shown in Table 4.1, a lower percentage of peak HR_{max} was achieved in CW simulations than either TCT (\(d = 1.25\)) or OD matches (\(d = 1.12\)). Mean HR was highest during TCT, and greater than CW simulations (\(d = 0.82\)) and OD matches (\(d = 1.32\)). This reflected a greater percentage of time spent above 75\%HR_{max} than the CW simulations (\(d = 0.65\) and 2.09) or OD matches (\(d = 0.28\) and 0.94), respectively. The greatest RPE resulted from OD matches with a moderate effect than the TCT (\(d = 0.55\)) and a large effect (\(d = 2.21\)) compared to CW simulations. A similar TL was calculated following TCT and OD matches with both reporting a large effect for a greater TL in comparison to CW simulations (\(d = 1.15\) and 2.17, respectively).

A greater relative distance was covered in OD matches than the TCT sessions (\(d = 0.62\)) and CW simulations (\(d = 0.97\)). A moderate effect (\(d = 0.56\)) was also reported for a greater relative total distance covered during TCT sessions opposed to CW simulations. There was a small effect (\(d = 0.47\)) for a greater HI distance to be covered during OD matches compared to TCT sessions, but there was a large effect (\(d = 1.11\)) for a greater HI distance covered compared to CW simulations. The greatest mean speed occurred during OD matches (Table 4.2), with moderate (\(d = 0.51\)) and large (\(d = 0.91\)) effects against TCT and CW simulations, respectively. A greater number of HI activities were performed during OD matches than TCT (\(d = 0.28\)) and CW simulations (\(d = 0.92\)). A moderate effect was present for a greater number of sprints performed during OD matches than TCT (\(d = 0.63\)) and CW simulations (\(d = 0.57\)). The work-to-recovery ratio of fielders was shortest during OD
matches, with a moderate effect for a shorter work-to-recovery ratio compared to TCT ($d = 0.57$) and a large effect compared to CW simulations ($d = 1.48$). Table 4.5 demonstrates that the overall and relative number of throws was greatest during traditional fielding sessions, resulting in a large effect for a greater number of throws compared to CW simulations ($d = 7.10$ and $4.68$) and OD matches ($d = 6.47$ and $5.02$), respectively.

**Wicketkeepers**

The greatest peak $\%HR_{\text{max}}$ was achieved during TCT than CW simulations ($d = 1.14$) and OD matches ($d = 1.43$). A greater $HR_{\text{mean}}$ was achieved during TCT, with a moderate effect reported ($d = 0.52$) with CW simulations and a large effect ($d = 1.75$) for OD matches. A similar RPE was observed between traditional wicketkeeping sessions and OD matches, showing small ($d = 0.50$) and moderate ($d = 0.70$) effects compared to CW simulations, respectively. The largest TL resulted from TCT, with a moderate effect for a greater TL reported when compared to CW simulations ($d = 0.62$) and OD matches ($d = 0.57$).

A large effect existed for greater relative distance covered and that covered within each movement category during CW simulations ($d = 1.38 \pm 0.36$) and OD matches ($d = 2.71 \pm 1.93$) than during TCT. This translated into a large effect for a higher mean speed (Table 4.2) during CW simulations ($d = 1.46$) and OD matches ($d = 1.92$). A greater mean speed was reported during OD matches with a large effect ($d = 0.86$) existing between CW simulations and OD matches. There were large effects for greater number of HI activities and sprints performed during OD matches compared to traditional wicketkeeping sessions.
and CW simulations \( (d = 0.90 \text{ and } 1.34) \), respectively. A large effect \( (d = 0.83) \) for a shorter work-to-recovery ratio during OD matches than CW simulations existed (Table 4.3). Only the relative number of throws per session showed a large effect during centre-wicket simulations compared to OD matches \( (d = 1.00) \) with a relatively greater number of throws completed during a CW simulation session.

**Discussion**

This study compared the physiological, physical and technical demands of elite cricket players during different training formats and matches within individual playing positions. As reported by Petersen et al. (2010), the physiological and physical responses as well as the technical responses in the current study, varied across each of the different formats. However, the differences in the training responses appear specific to each playing position. Overall, no single training modality (i.e. CW simulation or TCT) was more effective at providing players with an environment that specifically replicated the demands of a typical OD cricket match. Specifically, a greater physiological and physical load occurred during CW simulations opposed to TCT sessions for batsman. However, the greatest physiological and physical load experienced by medium-fast bowlers resulted from TCT sessions rather than CW simulations. In regards to spin bowlers, fielders and wicketkeepers, varied responses were observed regarding the most beneficial training format for the different physical and physiological measures. Collectively, the data identified that regardless of playing position, the greatest technical demands occurred during TCT. As such, the use of TCT methods provides cricket players with a physically and
technically match-intensive training environment when compared to CW simulations. However, this format does not place players in environment that is conducive to match-simulation, and does not challenge cognitive or tactical capacities.

**Batsmen**

Batsmen performed at a greater physical intensity with higher physiological demands during OD matches when compared to either training format. In particular, batsmen sustained a higher $HR_{\text{mean}}$ and performed a greater number of HI activities, allowing for an increased mean speed. The HR responses and movement characteristics reported for the OD match-play are similar to past studies reporting on international match-play (Nicholson et al., 2009; Petersen et al., 2010). However, the results also suggest that CW simulations provide batsmen with a training environment that is more replicable of a OD cricket match (Duffield & Drinkwater, 2008; Petersen et al., 2010) than traditional net-based training sessions. It is possible that the use of game-based training is more conducive to HI running due to the inclusion of running between the wickets as opposed to the practice of remaining stationary during TCT. This increased running demand of batsmen during CW simulations is likely to increase the HR responses of the batsmen. As such, a more match-intensive training environment is likely to occur for batsman during CW simulations based on the greater internal and external TL’s imposed due to the match-specific environment.
However, batsmen received greater opportunity to improve technical skill during net-based training. The relative number of balls faced during TCT sessions was approximately double that faced during CW simulations and OD match-play. Batsmen were also more likely to hit a greater percentage of balls that were faced during TCT (82%) than both CW simulation (68%) and OD matches (76%), suggesting a more aggressive approach to batting with a greater risk of being dismissed during traditional net-based batting sessions. Although a greater opportunity for increased technical training occurs during traditional net-based environments, the use of CW simulations provided a metabolic demand that was more representative of a typical OD match. Based on this evidence it is plausible to suggest that the use of CW game-simulations as a training format could provide cricket batsmen with a physically demanding training environment, whilst still providing a sufficient technical stimulus.

**Medium-Fast Bowlers**

Similar HR responses were reported between TCT and OD matches, particularly in the $HR_{\text{mean}}$ and relative time spent above 75%$HR_{\text{max}}$, which are comparable to that previously reported during net-based training sessions and competitive OD matches (Duffield et al., 2009; Petersen et al., 2010). The current evidence also suggests that the physical demands during the TCT sessions greatly exceeded those of medium-fast bowlers during OD matches. By comparison a lower physiological ($HR_{\text{mean}}$, time above 75%$HR_{\text{max}}$) and physical demand (mean speed, distance covered at a HI) resulted from CW practice when compared to the other formats. Based on these findings it appears that traditional net-based training sessions are more likely to provide
medium-fast bowlers with a greater TL than that of CW practice. However, given that the TL of medium-fast bowlers is of strong interest to conditioning staff due to injury prevention concerns (Dennis, Finch & Farhart, 2005).

The results also demonstrate large differences in technical demand TCT than CW simulations and OD matches, when expressed relative to session duration. This increased technical demand (relative number of balls faced and hit) during TCT most likely accounts for the increased physical demand of medium-fast bowlers. Therefore, it appears that TCT in the current study more closely replicates, and in some instances exceeds the physiological, physical and technical demands of a typical OD cricket match within the current study and previous research (Petersen et al., 2010). Unfortunately unlike CW simulations, TCT sessions lack the match-specific environment and those factors associated with game-based training such as game awareness and the use of specific match-scenarios and as such are not able to completely replicate match conditions. This is a major limitation of TCT and as suggested by Renshaw et al. (2010), it may limit the transference of decision-making ability and technical skill into an actual match-play.

**Spin Bowlers**

The relative physical load imposed on spin bowlers during CW simulations was typical of OD match-play, and more than TCT. Similarly, this was also demonstrated in the physiological responses of spin bowlers during the respective training formats and matches. A considerable difference exists in the physiological and physical demands resulting from the two training formats in
the current study. In particular, significantly more relative distance is covered at a HI during TCT opposed to CW simulations. Therefore, it appears that the demands placed upon elite spin bowlers during CW simulations may not provide a sufficient TL that can meet the demands of TCT or a typical match.

Further, a greater number of balls were bowled during TCT than OD matches. This was not observed for CW simulations, with considerably fewer deliveries being bowled during the entire training session when opposed to OD matches. Therefore, despite CW simulations being shown to be able to closely replicate the physiological and physical demands of OD matches, the volume of technical outcomes may not be sufficient for skill development. Coaches may want to consider increasing the technical demands of spin bowlers during CW simulations to create a match-intensive and technically demanding training environment, although this may then have a significant overall effect on the TL placed upon spin bowlers.

Fielders

Within the current study, a large disparity in the demands placed upon fielders in the training formats, with a considerably higher TL resulting from TCT methods. Furthermore, the current study also shows a considerably greater physiological load occurs during TCT opposed to a OD match, despite this not translating into a greater physical load. Despite the increased physiological demands, this lesser physical demand may be due to the decreased HI efforts completed by fielders combined with the longer recovery time between each effort. However, the results demonstrate that TCT more closely replicates a
match-intensive environment than CW simulations. Similar to medium-fast bowlers, TCT appears to provide a more suitable, match-appropriate TL for fielders, which is considerably greater than the TL which results from CW practice.

As in the study of Saw et al. (2009), significantly more throws were completed during traditional fielding sessions compared to OD matches and CW simulations. Based on this, it has been recommended that throwing workload be monitored to minimise the chance of throwing-related injuries (Saw et al., 2009). The results of the current study would suggest that the significantly greater number of throws completed during TCT sessions may increase the chance of injury. Therefore, the number of throws completed by fielders during CW simulations may be more appropriate in matching technical match demand. However, given the small number of throws completed during this training method, this may limit any improvements in throwing performance. As such, a compromise between TCT and CW simulations may be required in order to maintain a sufficient technical training volume for fielders.

**Wicketkeepers**

Compared to One-Day matches, the physiological load imposed on wicketkeepers appears greatest during TCT. Furthermore, the HR responses of wicketkeepers in the current study appear to be considerably lower than previously reported (Petersen et al., 2010). Within the current study, the increased HR during TCT was not combined with an increase in movement demands. It is possible the increased physiological demand is caused by the
numerous and constant small movements such as squatting and side-stepping, which are typical of wicketkeepers but may not be recorded by the GPS devices. By comparison, the physical demands of wicketkeepers during CW simulations showed an overall large effect for a decreased physical demand in contrast to OD matches which likely explains the similar physiological responses between the respective formats. In regards to the technical demands of wicketkeepers, there was little difference in the overall number of throws completed. It should however be noted, that measuring the number of throws completed by wicketkeepers is not be the most appropriate measure of skill. As has been suggested within other playing positions match-specific demands appear to be best replicated during TCT rather than CW simulations.

**Conclusion**

The major findings of this study suggest that the most beneficial training format for conditioning may be highly dependent on playing position. Varied physiological and physical responses were demonstrated within the current data, although collectively it suggests that TCT may provide the greatest TL for both medium-fast bowlers and fielders. However, for both batsmen and spin bowlers, it appeared that the most specific TL occurred from CW training. In regards to wicketkeepers, no single training method appeared to provide a superior conditioning stimulus, with varied physiological and physical responses demonstrated. Based on this data, it may be difficult to develop training programs with the aim of improving the conditioning status of players, and provide match-specific TL across each playing position.
Regardless of playing position, TCT was more likely to provide a greater technical and more match-specific training demand when compared to CW simulations. In turn, this may limit the development of technical skills of a player within a match-specific environment. A major limitation of TCT is that when compared to game-based training such as CW simulation, the inclusion of match-specific scenarios for developing match awareness is more difficult. It is well understood that for optimal training efficacy, the environment in which athletes train should as closely as possibly replicate the demands of an actual match (Reilly et al., 2009). Therefore to ensure that players are placed within a match-specific training environment whilst concurrently gaining a conditioning and technical training stimulus, cricket coaches may need to consider increasing the intensity of CW simulation sessions.

**Practical Applications**

- Neither training format (TCT sessions or CW simulations) consistently provided a match-specific training environment for any playing positions.

- The use of TCT methods and CW simulation training provided varied conditioning responses with the greatest responses observed for batsmen and spin bowlers using CW practice, and TCT for medium-fast bowlers and fielders.

- Regardless of playing position, the technical demands of TCT are more than suitable at replicating that which occurs during a OD cricket match, whereas this was not the case during CW simulations.
• Increasing the ecological validity of the cricket training environment is likely to increase the concurrent development of each player’s fitness and technical skill capacities.

• As within other team sports, cricket coaches may want to explore the use of SSG with set constraints rather than the open CW simulations to provide players with a match-specific training environment to best develop physical fitness, technical skill and tactical awareness.
Chapter 5

Study 3

Battlezone: An examination of the physiological responses, movement demands and reproducibility of small-sided cricket games

As per the peer-reviewed paper Accepted and Published in the Journal of Sports Sciences:

Abstract

Typically the current cricket training methods such as net- and game-based sessions used do little to replicate match-play. The use of SSG in various team sports has been shown to provide a training stimulus that is replicative of match-play. This study reported on the movement demands, physiological responses and reproducibility of the demands of small-sided cricket games. Thirteen amateur, male cricket players (age: 22.8 ± 3.5 yr, height: 1.78 ± 0.06 m, body mass: 78.6 ± 7.1 kg) completed two sessions of a generic small-sided cricket game, termed BZ; consisting of six repeat 8-over bouts. Heart rate and movement demands were continuously recorded, whilst [BLa] and RPE were recorded after each respective bout. Batsmen covered the greatest distance (1147 ± 175 m) and demonstrated the greatest mean speed (63 ± 9 m min⁻¹) during an 8-over bout. By comparison, medium-fast bowlers covered 1102 ± 250 m during each bout, which translated into a mean speed of 60 ± 10 m min⁻¹. Across all playing positions, the majority of time (79-90%) was spent working with a HR of between 51-85%HRmax and [BLa] between 1.1-2.0 mmol L⁻¹. Specifically, batsmen performed for the least amount of time within this HR range (79 ± 61%) when compared to the other playing positions. This resulted from the considerably greater time spent performing above 85%HRmax by batsmen (20 ± 27%). Ratings of perceived exertion ranged between 4.2-6.0, with batsmen reporting the lowest mean RPE across both BZ sessions (4.4 ± 1.3) in comparison to medium-fast bowlers (5.2 ± 1.2) and spin bowlers (5.3 ± 0.4). Movement demands and physiological responses did not differ between standardised sessions within respective playing positions (p > 0.05). The reliability for the majority of movement demands and physiological responses
were demonstrated to be moderate to high within all playing positions. Specifically, mean speed (CV: 7-9%; ICC: 0.56-1.00) and peak %HR<sub>max</sub> achieved (CV: 6-8%; ICC: -0.80-0.73) demonstrated acceptable reliability across each playing position. These results suggest that the physiological responses and movement characteristics of generic cricket SSG were consistent between sessions within respective playing positions.

**Introduction**

Replication of competitive match demands is often viewed as an appropriate and beneficial training stimulus (Gabbett et al., 2009; Gabbett, 2008). Typically this has come in the form of game-based training which involves placing players into an environment which creates match-like scenarios. This may include game-specific drills or playing an actual match within a training context (Gabbett et al., 2009). Somewhat similar to game-based training, SSG are an increasingly popular training method that are used to replicate technical skills and tactical awareness, whilst also providing a physiological stimulus typical of a competitive match (Davids et al., 2013; Gabbett et al., 2009). Further, the periodised use of SSG may include modifying constraints such as the area of a playing field, player numbers or match rules to alter the physiological, physical and technical demands (Hill-Haas et al., 2011). For football related sports, SSG appear equally effective at improving physical fitness and match performance when compared to traditional conditioning and skill-based training methods (Dellal et al., 2008; Impellizzeri et al., 2006). Previous research has also
reported that these responses are reproducible both between and within training sessions in soccer (Hill-Haas et al., 2008b).

Previously in Study 2, the use of game-based training for cricket in the form of CW simulations demonstrated varied physical and physiological responses across the different playing positions, some that did not reflect the demands of a typical OD cricket match. As such, it was recommended a more match-specific training environment be developed to better facilitate the concurrent development of a player’s physical fitness and technical ability. Recently, a SSG approach to cricket training has been developed and termed BZ (Renshaw et al., 2010). These researchers proposed that BZ allows players to acquire cricket-specific skills in an intensive match-simulation environment. Such a training environment may facilitate a greater transference of learnt skills into match-play (Renshaw et al., 2010). Typically, cricket training places a greater emphasis on technical abilities rather than physical or physiological demands (Bartlett, 2003; Stretch et al., 2000). As such, training practices typical of cricket have reflected this preference of technical proficiency (Woolmer, Noakes & Moffett, 2009). Cricket training has traditionally involved structured net sessions combined with separate fielding drills and structured conditioning sessions that have not attempted to replicate the demands of specific match conditions (Pyke & Davis, 2010). Recently, Petersen et al. (2010) reported a large percentage of LI activity interspersed with intermittent, short sprints was associated with cricket match-play, regardless of the playing format. In the same study, it was also established that the demands of cricket player’s vary between playing positions, with medium-fast bowlers typically completing the greatest workload.
(Petersen et al., 2010). Furthermore, as the length of the match decreases, the playing intensity of the players appears to increase (Petersen et al., 2010).

Given the expansion of cricket and the increase in the number of shorter format cricket matches, it may be suggested that the training practices adopted by cricket teams need to evolve to reflect match characteristics (Fletcher, 1955; Petersen et al., 2010). Furthermore, the current game-based training practices currently used by cricket coaches (CW simulations) are not suitable at providing a consistent match-appropriate TL (Study 2). Other FBTS such as soccer and rugby league have employed SSG to provide a training environment that simulates externally valid technical and tactical scenarios, whilst applying physical demands that are representative of competitive match-play. However, at present the physical and physiological demands of BZ remain unknown, making it difficult to suggest whether a sufficient physiological stimulus that replicates match demands is provided. Therefore, the primary aim of this study was to report on the physical and physiological demands of BZ in cricket players. Secondly, the research also aimed to quantify the reproducibility of these demands between repeated generic BZ sessions.

**Methods**

**Participants**

Thirteen amateur, male cricket players (age: 22.8 ± 3.5 yr, height: 1.78 ± 0.06 m, body mass: 78.6 ± 7.1 kg) were recruited to complete the training. All participants were selected to play first or second grade within a suburban competition, and completed two cricket-specific training sessions per week.
Participants gave verbal and written informed consent (see Appendix C) prior to any testing. The research was approved by the University of Newcastle Human Research Ethics Committee (H-2010-1288) (see Appendix D).

**Procedure**

Following an initial familiarisation session, all participants completed two BZ sessions that were separated by seven days on a prepared, turf cricket pitch in similar environmental conditions (21.1 ± 1.3°C). Unlike CW simulations (detailed in Study 2), which were performed on an entire cricket field, a 0.8 m high cricket net was placed around the 30 yd inner circle line of a standard cricket field (International Cricket Council, 2009). Additionally each BZ session consisted of six repeat bouts, with each bout consisting of 8 overs and lasting 18 ± 2 min. The repeat bouts were separated by 5 min of passive rest. Participants were classified as a batsman, medium-fast bowler, spin bowler, fielder or wicketkeeper according to their role during each bout. A total of eight participants were on the field at any one time. One bout of BZ required two bowlers to complete four alternating overs to a batting pair. Fielders were positioned at backward point, cover, mid-wicket and wicketkeeper. When not bowling, bowlers were situated at mid-off, but still classified as bowlers (Figure 5.1, over the page). All participants batted during at least one bout, with two participants batting during two non-consecutive bouts. Three bowlers bowled a minimum of two spells (8 overs in total) with a further two bowlers completing 4 extra overs. Two wicketkeepers were used throughout each session; each keeping for 3 bouts in total. Those not taking part in an 8-over bout were allowed to rest outside of the BZ playing field. The sequence in which all
participants performed the respective BZ bouts was identical between the two data collection periods.

**Figure 5.1:** Layout of BZ playing area for a right-handed batsmen.

The BZ session chosen represented a scenario typically observed within the inner circle of the middle section of a OD cricket match. All BZ sessions were completed under the rules governing cricket match-play (International Cricket Council, 2009). Batsmen were instructed to score as many runs as possible and were encouraged to hit the ball along the ground as often as possible and not over the net as per developing match-specific technique. If dismissed, batsmen changed ends and play continued. Bowlers were instructed to restrict the amount of runs scored and to dismiss the batsmen during their bowling spell.
Fielders were instructed to attempt a run-out at either end of the pitch each time the batsmen attempted to score. If no run was attempted, fielders were required to throw the ball to the wicketkeeper. If during a bout, the batting pair was a combination of a right- and left-handed batsmen, the fielders were required to move accordingly to maintain the same field setting. When a ball was hit or thrown over the surrounding net, participants were instructed towards spare cricket balls placed on the exterior of the net in line with the popping crease at both ends and sides of the playing field (see Figure 5.1).

Physiological Measures
Heart rate was recorded at 5 s intervals across both BZ sessions using a Polar Team² System (Polar Electro Oy, Kempele, Finland). Prior to the BZ sessions, all participants completed the Yo-Yo Intermittent Recovery Test Level 1 whilst wearing a HR monitor to determine their individual HR$_{\text{max}}$. Absolute and relative time spent in HR zones (Zone 1 [0-50%HR$_{\text{max}}$], Zone 2 [51-75%HR$_{\text{max}}$], Zone 3 [76-85%HR$_{\text{max}}$], Zone 4 [86-95%HR$_{\text{max}}$] and Zone 5 [>95%HR$_{\text{max}}$]) were calculated for each participant during each BZ bout. At the end of each bout, capillary blood samples (~5 µL) were drawn from a hyperaemic earlobe of all batsmen and bowlers and analysed for [BLa] (Lactate Scout, EKF Diagnostics, Magdeburg, Germany). Following each bout, all batsmen and bowlers were required to provide a RPE using the CR-10 scale (Borg et al., 1987).

Time-Motion Characteristics
The movement demands of BZ were quantified using 10 Hz MinimaxX GPS devices (Catapult Innovations, Melbourne, Australia). All participants wore a
harness that located the unit between the scapulae. Each GPS device was turned on in an open area 15 min prior to participants being fitted with the units to ensure a satellite lock was established. Data were downloaded and analysed following each BZ session using the Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia).

All movement data was calculated as time spent and distance covered in ascending movement zones (standing/walking [0-2.00 m·s⁻¹], jogging [2.01-3.50 m·s⁻¹], running [3.51-4.00 m·s⁻¹], striding [4.01-5.00 m·s⁻¹] and sprinting [>5.01 m·s⁻¹]) (Petersen et al., 2010). Work-to-recovery ratio was defined as the ratio of time spent completing HI (running, striding, sprinting) to LI (standing/walking, jogging) activities as per Petersen et al. (2010). The initial increase in velocity of the bowler who delivered the first ball of the bout, and when no increase in velocity after the final ball was delivered of the bout using Logan 4.6 software (Catapult Innovations, Melbourne, Australia) signified the start and end point, respectively of each 8-over bout.

**Statistical Analysis**

All data were reported as mean ± SD. Any data recorded whilst a participant was not directly involved in a BZ bout was not reported and not included in analyses. Independent samples t-tests (p < 0.05) were used to determine if movement demands and physiological responses differed between each playing position across sessions. Within position comparisons were made using paired samples t-tests (p < 0.05). As outlined in Hopkins (2000), the variability of each measure was calculated using the typical error of measurement and
expressed as CV. Intra-class correlation was used to assess between-session reliability. Statistical analyses were performed using the software package IBM SPSS Statistics (version 19, IBM Corporation, Somers, New York, USA) and a customised spreadsheet in Microsoft Excel 2003® developed by Hopkins (2009).

Results

Physiological Measures

Physiological responses recorded during generic BZ bouts are presented in Table 5.1 (see page 123). Across all playing positions, the %HR\textsubscript{max} ranged from 78-89%; however, the majority of total time (74-92%) was spent within HR Zone 2 and 3 (51-85%HR\textsubscript{max}) (Table 5.1). Fielders and wicketkeepers spent an increased percentage of time ($p < 0.05$) within the HR Zones 1, 2 and 3 when compared to batsmen, medium-fast bowlers and spin bowlers. The highest %HR\textsubscript{max} of fielders and wicketkeepers also significantly differed ($p < 0.05$) to batsmen and medium-fast bowlers, respectively. All other measures, including post-bout [BLa\textsuperscript{-}] and RPE were not significantly different between each playing position ($p > 0.05$).

Movement Demands

The total distances covered and mean speeds of each playing position during BZ training are presented in Table 5.2 (see page 124). Batsmen covered the greatest total (1147 ± 175 m) and HI activity (225 ± 117 m) distances per 8-over bout. Medium-fast bowlers covered a similar total distance to that of batsmen ($p > 0.05$). Wicketkeepers covered the least total distance (454 ± 258 m) compared to all other positions ($p < 0.05$). Interestingly, wicketkeepers
completed 428 ± 239 m of LI activity, which was relatively similar to the other playing positions (batsmen: 80%; medium-fast bowlers: 90%; spin bowlers: 91%; fielders: 82% and wicketkeepers: 94%). Similarly, batsmen achieved the highest mean speed (63 ± 9 m·min⁻¹) per BZ bout, followed by medium-fast bowlers (60 ± 10 m·min⁻¹). In comparison, fielders and wicketkeepers reported significantly ($p < 0.05$) lower mean speeds per bout to batsmen and medium-fast bowlers. Wicketkeepers also achieved a significantly lower ($p < 0.05$) maximal speed (3.8 ± 1.5 m·s⁻¹) in comparison to batsmen, medium-fast bowlers and fielders. Significantly different ($p < 0.05$) distances at running, striding and sprinting speeds were observed between batsmen, fielders and wicketkeepers, resulting in the greater distances within the HI activity zone.
Table 5.1: Physiological and perceptual responses by position during a generic Battlezone bout (mean ± SD).

<table>
<thead>
<tr>
<th>Position</th>
<th>Session</th>
<th>Peak %HR&lt;sub&gt;max&lt;/sub&gt;</th>
<th>Zone 1 (%)</th>
<th>Zone 2 (%)</th>
<th>Zone 3 (%)</th>
<th>Zone 4 (%)</th>
<th>Zone 5 (%)</th>
<th>[BLA] (mmol L&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>RPE (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batsman (n=20)</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>1</td>
<td>91 ± 6</td>
<td>0</td>
<td>45 ± 40</td>
<td>29 ± 26</td>
<td>23 ± 29</td>
<td>1 ± 3</td>
<td>1.5 ± 0.5</td>
<td>4.2 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>87 ± 5</td>
<td>3 ± 8</td>
<td>50 ± 32</td>
<td>33 ± 23</td>
<td>14 ± 20</td>
<td>0</td>
<td>2.0 ± 0.9</td>
<td>4.6 ± 0.9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>89 ± 6</td>
<td>2 ± 4</td>
<td>48 ± 36</td>
<td>31 ± 25</td>
<td>19 ± 25</td>
<td>1 ± 2</td>
<td>1.8 ± 0.7</td>
<td>4.4 ± 1.3</td>
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<tr>
<td>Medium-fast bowler (n=8)</td>
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<tr>
<td></td>
<td>1</td>
<td>90 ± 10</td>
<td>0</td>
<td>46 ± 21</td>
<td>33 ± 11</td>
<td>19 ± 21</td>
<td>1 ± 2</td>
<td>2.0 ± 0.9</td>
<td>5.6 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>88 ± 0</td>
<td>2 ± 4</td>
<td>75 ± 18</td>
<td>21 ± 13</td>
<td>2 ± 3</td>
<td>0</td>
<td>1.6 ± 0.3</td>
<td>4.7 ± 1.3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>89 ± 5</td>
<td>1 ± 2</td>
<td>59 ± 20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27 ± 12</td>
<td>11 ± 12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1 ± 1</td>
<td>1.8 ± 0.6</td>
<td>5.2 ± 1.2</td>
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<tr>
<td>Spin bowler (n=2)</td>
<td></td>
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<tr>
<td></td>
<td>1</td>
<td>83 ± 10</td>
<td>7 ± 10</td>
<td>91 ± 58</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>0</td>
<td>1.1 ± 0.4</td>
<td>4.5 ± 0.7</td>
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<tr>
<td></td>
<td>2</td>
<td>91 ± 1</td>
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<td>45 ± 24</td>
<td>43 ± 23</td>
<td>5 ± 6</td>
<td>0</td>
<td>1.6 ± 0.4</td>
<td>6.0 ± 0.0</td>
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<tr>
<td>Mean</td>
<td></td>
<td>87 ± 6</td>
<td>4 ± 5</td>
<td>68 ± 41</td>
<td>22 ± 12</td>
<td>3 ± 4</td>
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<td>1.4 ± 0.4</td>
<td>5.3 ± 0.4</td>
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<tr>
<td>Fielder (n=18)</td>
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<tr>
<td></td>
<td>1</td>
<td>78 ± 8</td>
<td>7 ± 21</td>
<td>67 ± 32</td>
<td>14 ± 16</td>
<td>4 ± 8</td>
<td>0</td>
<td></td>
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<tr>
<td></td>
<td>2</td>
<td>78 ± 9</td>
<td>8 ± 12</td>
<td>80 ± 19</td>
<td>8 ± 11</td>
<td>2 ± 6</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>78 ± 9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8 ± 17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>74 ± 26&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11 ± 14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3 ± 7</td>
<td>0&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wicketkeeper (n=2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>80 ± 3</td>
<td>0</td>
<td>71 ± 39</td>
<td>12 ± 18</td>
<td>0 ± 1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>76 ± 6</td>
<td>13 ± 17</td>
<td>80 ± 20</td>
<td>5 ± 11</td>
<td>2 ± 4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>78 ± 5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7 ± 9</td>
<td>76 ± 30&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>9 ± 15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1 ± 3</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significantly (*p* < 0.05) different (between sessions within playing position); <sup>a</sup> Significantly (*p* < 0.05) different to batsmen; <sup>b</sup> Significantly different to medium-fast bowlers; <sup>c</sup> Significantly (*p* < 0.05) different to spin bowlers.
Table 5.2: Total distances covered in each movement category across playing positions during a generic Battlezone bout (mean ± SD).

<table>
<thead>
<tr>
<th>Position</th>
<th>Session</th>
<th>Walking (m)</th>
<th>Jogging (m)</th>
<th>Running (m)</th>
<th>Striding (m)</th>
<th>Sprinting (m)</th>
<th>Total Distance (m)</th>
<th>LI Distance (m)</th>
<th>HI Distance (m)</th>
<th>Mean Speed (m min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batsman (n=20)</td>
<td>1</td>
<td>574 ± 80</td>
<td>350 ± 38</td>
<td>98 ± 33</td>
<td>102 ± 81</td>
<td>21 ± 33</td>
<td>1153 ± 185</td>
<td>924 ± 79</td>
<td>224 ± 140</td>
<td>59 ± 9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>557 ± 29</td>
<td>352 ± 53</td>
<td>109 ± 29</td>
<td>95 ± 52</td>
<td>21 ± 20</td>
<td>1140 ± 165</td>
<td>909 ± 90</td>
<td>225 ± 93</td>
<td>66 ± 8</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>566 ± 55</td>
<td>351 ± 46</td>
<td>104 ± 31</td>
<td>99 ± 67</td>
<td>21 ± 27</td>
<td>1147 ± 175</td>
<td>917 ± 85</td>
<td>225 ± 117</td>
<td>63 ± 9</td>
</tr>
<tr>
<td>Medium-fast bowler (n=8)</td>
<td>1</td>
<td>793 ± 165</td>
<td>190 ± 55</td>
<td>71 ± 34</td>
<td>83 ± 47</td>
<td>27 ± 22</td>
<td>1189 ± 237</td>
<td>983 ± 213</td>
<td>199 ± 52</td>
<td>60 ± 10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>689 ± 143</td>
<td>221 ± 66</td>
<td>46 ± 38</td>
<td>33 ± 24</td>
<td>21 ± 40</td>
<td>1014 ± 263</td>
<td>910 ± 202</td>
<td>100 ± 70</td>
<td>59 ± 10</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>741 ± 154</td>
<td>206 ± 61a</td>
<td>59 ± 36</td>
<td>58 ± 36</td>
<td>24 ± 31</td>
<td>1102 ± 250</td>
<td>947 ± 208</td>
<td>150 ± 61</td>
<td>60 ± 10</td>
</tr>
<tr>
<td>Spin bowler (n=2)</td>
<td>1</td>
<td>587 ± 212</td>
<td>51 ± 17</td>
<td>14 ± 4</td>
<td>29 ± 11</td>
<td>16 ± 2</td>
<td>699 ± 218</td>
<td>638 ± 229</td>
<td>58 ± 13</td>
<td>38 ± 2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>694 ± 76</td>
<td>136 ± 16</td>
<td>19 ± 15</td>
<td>41 ± 13</td>
<td>18 ± 25</td>
<td>907 ± 146</td>
<td>830 ± 93</td>
<td>77 ± 54</td>
<td>48 ± 1</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>641 ± 144</td>
<td>94 ± 17a</td>
<td>17 ± 10a</td>
<td>35 ± 12a</td>
<td>17 ± 14</td>
<td>803 ± 182</td>
<td>734 ± 161</td>
<td>68 ± 34a</td>
<td>43 ± 2</td>
</tr>
<tr>
<td>Fielder (n=18)</td>
<td>1</td>
<td>588 ± 274</td>
<td>195 ± 163</td>
<td>42 ± 33</td>
<td>58 ± 60</td>
<td>23 ± 36</td>
<td>909 ± 476</td>
<td>734 ± 403</td>
<td>123 ± 116</td>
<td>47 ± 23</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>550 ± 246</td>
<td>172 ± 114</td>
<td>43 ± 26</td>
<td>62 ± 47</td>
<td>28 ± 32</td>
<td>860 ± 395</td>
<td>722 ± 336</td>
<td>134 ± 100</td>
<td>49 ± 20</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>481 ± 260</td>
<td>184 ± 139a</td>
<td>43 ± 30a,d</td>
<td>60 ± 54a,d</td>
<td>26 ± 34a,d</td>
<td>885 ± 436a,d</td>
<td>728 ± 370a</td>
<td>129 ± 108a</td>
<td>48 ± 23</td>
</tr>
<tr>
<td>Wicketkeeper (n=2)</td>
<td>1</td>
<td>397 ± 238</td>
<td>42 ± 53</td>
<td>6 ± 7</td>
<td>10 ± 13</td>
<td>2 ± 3</td>
<td>458 ± 300</td>
<td>439 ± 285</td>
<td>18 ± 22</td>
<td>24 ± 17</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>378 ± 160</td>
<td>40 ± 33</td>
<td>9 ± 7</td>
<td>19 ± 16</td>
<td>3 ± 3</td>
<td>450 ± 216</td>
<td>417 ± 193</td>
<td>31 ± 25</td>
<td>26 ± 12</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>388 ± 199a, b,c</td>
<td>41 ± 43a,b,c</td>
<td>8 ± 7a</td>
<td>15 ± 15a</td>
<td>3 ± 3ab,c</td>
<td>454 ± 258a,b</td>
<td>428 ± 239ab,d</td>
<td>25 ± 24abc,d</td>
<td>25 ± 15ab</td>
</tr>
</tbody>
</table>

* Significantly (p < 0.05) different between sessions within playing position; a Significantly (p < 0.05) different to batsmen; b Significantly (p < 0.05) different to medium-fast bowlers; c Significantly (p < 0.05) different to spin bowlers; d Significantly different (p < 0.05) to fielders.
Further movement characteristics of all playing positions are presented in Table 5.3 (see over the page). The number of HI efforts completed by batsmen significantly differed \((p < 0.05)\) to that completed by spin bowlers, fielders and wicketkeepers. The work-to-recovery ratio ranged from \(23 \pm 11\) s for batsmen to \(179 \pm 88\) s for wicketkeepers per BZ bout \((p < 0.05)\). This translated into significantly \((p < 0.05)\) shorter recovery times between HI efforts for batsmen when compared to spin bowlers, fielders and wicketkeepers.
Table 5.3: Movement characteristics by position during a generic Battlezone bout (mean ± SD).

<table>
<thead>
<tr>
<th>Position</th>
<th>Session</th>
<th>HI Efforts (#)</th>
<th>Sprints (#)</th>
<th>Maximal Speed (m·s⁻¹)</th>
<th>Mean Sprint Distance (m)</th>
<th>Work-to-Recovery Ratio (1:x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batsman (n=20)</td>
<td>1</td>
<td>38 ± 24</td>
<td>3 ± 3</td>
<td>5.2 ± 0.5</td>
<td>5 ± 4</td>
<td>25 ± 11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>40 ± 16</td>
<td>3 ± 3</td>
<td>5.2 ± 0.6</td>
<td>5 ± 3</td>
<td>21 ± 10</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>39 ± 20</td>
<td>3 ± 3</td>
<td>5.2 ± 0.5</td>
<td>5 ± 4</td>
<td>23 ± 11</td>
</tr>
<tr>
<td>Medium-fast bowler (n=8)</td>
<td>1</td>
<td>34 ± 10</td>
<td>3 ± 3</td>
<td>5.5 ± 0.3</td>
<td>11 ± 4</td>
<td>32 ± 25</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16 ± 12</td>
<td>2 ± 3</td>
<td>5.1 ± 0.8</td>
<td>4 ± 6</td>
<td>59 ± 33</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>25 ± 11¹</td>
<td>3 ± 3</td>
<td>5.3 ± 0.6</td>
<td>8 ± 5</td>
<td>46 ± 29</td>
</tr>
<tr>
<td>Spin bowler (n=2)</td>
<td>1</td>
<td>9 ± 2</td>
<td>1 ± 1</td>
<td>5.7 ± 0.1</td>
<td>15 ± 3</td>
<td>89 ± 43</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12 ± 6</td>
<td>2 ± 2</td>
<td>5.0 ± 0.5</td>
<td>6 ± 8</td>
<td>78 ± 40</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>11 ± 4²</td>
<td>2 ± 2</td>
<td>5.3 ± 0.5</td>
<td>11 ± 6</td>
<td>84 ± 42²</td>
</tr>
<tr>
<td>Fielder (n=18)</td>
<td>1</td>
<td>17 ± 14</td>
<td>2 ± 3</td>
<td>5.1 ± 0.9</td>
<td>6 ± 6</td>
<td>51 ± 50</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>21 ± 15</td>
<td>3 ± 3</td>
<td>5.4 ± 0.8</td>
<td>7 ± 6</td>
<td>57 ± 48</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>19 ± 15³</td>
<td>3 ± 3</td>
<td>5.2 ± 0.9</td>
<td>7 ± 6</td>
<td>54 ± 49³</td>
</tr>
<tr>
<td>Wicketkeeper (n=2)</td>
<td>1</td>
<td>4 ± 4</td>
<td>1 ± 1</td>
<td>3.7 ± 1.5</td>
<td>2 ± 3</td>
<td>255 ± 142</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5 ± 4</td>
<td>1 ± 1</td>
<td>3.9 ± 1.7</td>
<td>3 ± 3</td>
<td>102 ± 33</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>5 ± 4</td>
<td>1 ± 1</td>
<td>3.8 ± 1.5</td>
<td>3 ± 3</td>
<td>179 ± 88³</td>
</tr>
</tbody>
</table>

¹ Significantly (p < 0.05) different between sessions within playing position; ² Significantly (p < 0.05) different to batsmen; ³ Significantly (p < 0.05) different to medium-fast bowlers; ⁴ Significantly (p < 0.05) different to fielders
Variability between BZ Sessions

Within-position reliability between generic BZ sessions for all movement demands and physiological responses are presented in Tables 5.1-5.3. Significant differences were observed within each respective position ($p < 0.05$) for the time spent in HR Zones 2 and 4, striding distance and the number of HI efforts of medium-fast bowlers. All other measures displayed no difference ($p > 0.05$) between BZ sessions within playing position. Measures of reproducibility from the physical and physiological data recorded during the generic BZ sessions are presented in Table 5.4 over the page. Both mean speed (CV: 7-9%) and total distance (5-17%) demonstrated acceptable variability across all playing positions in the current study. The most variable measure was the number of HI efforts completed during a bout, which possessed a %CV ranging between 53-114% across the various playing positions. However, the majority of measures possessed a moderate to high level of reliability ($r = 0.48-1.00$). Further, a greater number of measures demonstrated a high level of reliability in batsmen and fielders when compared to medium-fast bowlers and wicketkeepers. Mean speed ($\text{m}\cdot\text{min}^{-1}$) was the most reliable measure across all playing positions with ICC ranging between $r = 0.72-1.00$. Total distance was also highly reliable across batsmen, fielders and wicketkeepers ($r = 0.89-0.97$), but not medium-fast bowlers ($r = 0.01$).
Table 5.4: Co-efficient of variance and intra-class correlation analysis between generic Battlezone sessions.

<table>
<thead>
<tr>
<th>Position</th>
<th>CV (%)</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batsmen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>4.9</td>
<td>0.90</td>
</tr>
<tr>
<td>Mean speed (m/min⁻¹)</td>
<td>9.4</td>
<td>0.56</td>
</tr>
<tr>
<td>HI Efforts (#)</td>
<td>56.7</td>
<td>-0.17</td>
</tr>
<tr>
<td>Work-to-Recovery Ratio (1:x)</td>
<td>66.3</td>
<td>0.12</td>
</tr>
<tr>
<td>[BLa] (mmol L⁻¹)</td>
<td>23.5</td>
<td>0.37</td>
</tr>
<tr>
<td>RPE (AU)</td>
<td>19.9</td>
<td>0.68</td>
</tr>
<tr>
<td>Highest %HRₘₐₓ</td>
<td>5.7</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Medium-fast bowlers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>11.4</td>
<td>0.01</td>
</tr>
<tr>
<td>Mean speed (m/min⁻¹)</td>
<td>8.0</td>
<td>0.72</td>
</tr>
<tr>
<td>HI Efforts (#)</td>
<td>52.5</td>
<td>0.60</td>
</tr>
<tr>
<td>Work-to-Recovery Ratio (1:x)</td>
<td>66.3</td>
<td>0.12</td>
</tr>
<tr>
<td>[BLa] (mmol L⁻¹)</td>
<td>25.8</td>
<td>0.48</td>
</tr>
<tr>
<td>RPE (AU)</td>
<td>24.4</td>
<td>-0.60</td>
</tr>
<tr>
<td>Highest %HRₘₐₓ</td>
<td>5.9</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Fielders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>16.3</td>
<td>0.89</td>
</tr>
<tr>
<td>Mean speed (m/min⁻¹)</td>
<td>6.7</td>
<td>0.96</td>
</tr>
<tr>
<td>HI Efforts (#)</td>
<td>114.3</td>
<td>0.70</td>
</tr>
<tr>
<td>Work-to-Recovery Ratio (1:x)</td>
<td>66.3</td>
<td>0.12</td>
</tr>
<tr>
<td>Highest %HRₘₐₓ</td>
<td>8.1</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Wicketkeepers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>16.3</td>
<td>0.97</td>
</tr>
<tr>
<td>Mean speed (m/min⁻¹)</td>
<td>6.7</td>
<td>1.00</td>
</tr>
<tr>
<td>HI Efforts (#)</td>
<td>98.1</td>
<td>0.31</td>
</tr>
<tr>
<td>Work-to-Recovery Ratio (1:x)</td>
<td>66.3</td>
<td>0.12</td>
</tr>
<tr>
<td>Highest %HRₘₐₓ</td>
<td>8.1</td>
<td>-0.80</td>
</tr>
</tbody>
</table>

**Discussion**

The primary aim of Study 3 was to quantify the physiological and physical responses of a cricket-based SSG to determine whether it provided a suitable training stimulus. Secondly, this research aimed to report on the reproducibility of these measures between repeated BZ sessions. The main finding of the study was that across all playing positions, the majority of time was spent at intensities between 51-85%HRₘₐₓ, whilst [BLa] and RPE for both batsmen and
bowlers ranged between 1.1-2.0 mmol·L⁻¹ and 4.2-6.0, respectively. Furthermore, the total distance travelled across each 8-over block ranged from 450-1189 m, with mean speeds during BZ ranging between 24-66 m·min⁻¹. A secondary finding of the current study was that many of the physiological and movement demands exhibited satisfactory reliability, regardless of playing position during a generic BZ session. Importantly, only measures of HI activity demonstrated a high level of variability. Taken together, these data suggest that BZ training provides an adequate and reliable physical conditioning stimulus for cricket players.

**Physiological Responses and Movement Demands**

**Batsmen**

Of all the playing positions, batsmen performed at the highest intensities and demonstrated elevated physiological responses during the generic BZ training. The majority of time (~79%) was spent working within HR Zones 2 and 3, suggesting that a consistent and moderate physiological intensity was maintained. In comparison to the CW simulations used in Study 2, a greater amount of time spent performing at a higher HR intensity by batsmen during a generic BZ session (CW: 88 ± 47%). Similar to this, Nicholson et al. (2009) reported that batsmen spent the majority of their time at low to moderate intensities (≤85%HR_max: 84.1 ± 9.7%; >85%HR_max: 19.7 ± 6.9%), during an actual OD cricket match. Separately, while [BLa⁻] has been used to reflect the HI physiological demands of cricket, only Petersen et al. (2011a) have reported [BLa⁻] values specific for cricket training. Despite no distinction between playing positions, the [BLa⁻] reported for the match-simulation employed by Petersen et
al. (2011a) (2.0 ± 0.5 mmol·L⁻¹) were similar to that of batsmen in the current study. However, the relatively low [BLa⁺] of the batsmen in the current study suggest that the physical demands required for a generic BZ session is not heavily reliant on anaerobic metabolism. Taken together, this physiological data suggests that the intensity of a generic BZ session is moderate, despite being interspersed with small periods of HI activity. As has been previously reported within the studies of Petersen et al. (2010; 2009b; 2011b) and as shown in the results of Study 2, this intermittent nature of cricket batsmen during a generic BZ setting is similar to that reported for actual cricket match-play.

While limited data exists reporting on RPE of cricket batsmen, the current study reported data corresponding to a rating of ‘somewhat-hard’ (4.4 ± 1.3). When compared to that within Study 2, BZ actually demonstrated a greater perceptual response than either a OD cricket match (3.4 ± 0.9) or CW simulation (2.7 ± 0.9). The perceived intensity within the current study was similar to that reported for a cricket training simulation from Houghton et al. (2011b), although this research used Borg’s original 15-point scale. Therefore, this may suggest BZ provides similar perceptual responses from batsmen as a batting protocol designed to mimic match demands, albeit within a shorter training time.

Furthermore, batsmen travelled a considerably greater distance and demonstrated the highest mean speed during a generic BZ bout when compared to the other playing positions. Additionally, batsmen within Study 2 travelled considerably less distance and at a lower mean speed during CW practice (relative total distance: 2284 ± 309 m·h⁻¹; mean speed: 38 ± 5 m·min⁻¹)
when compared to batsmen performing in a generic BZ session (relative total distance: 3785 ± 578 m h^{-1}; mean speed: 63 ± 9 m min^{-1}). This is most likely the result of batsmen completing a high number of HI efforts during a BZ training session, in an attempt to secure the greatest amount of runs in an innings. This helps to further replicate the match awareness required for the shorter versions of cricket such as T20. It is also possible that the BZ format itself allows batsmen to score more freely due to the fewer number of fielders, which may be a favourable physical stimulus for batsmen. As a result, batsmen spent considerably less time walking (~50%) when compared to the bowlers and wicketkeeper. Despite the obvious difference in competitive standards, when compared to OD International batsmen (Petersen et al., 2010), the current study suggests that a similar amount of time is spent performing HI movements during a generic BZ bout. Furthermore, batsmen in BZ demonstrated a greater mean speed than that reported for a OD International (Petersen et al., 2010). Taken together, it seems that a generic BZ session provides batsmen with a physically demanding training environment that is representative of match-play, and exceeds that reported for CW simulations as highlighted in Study 2.

**Medium-Fast Bowlers**

In the current study, medium-fast bowlers spent the majority of time (~86%) working in HR Zones 2 and 3, suggesting that the HR data was comparable to previous data on fast-bowling training protocols (Burnett et al., 1995; Duffield et al., 2009; Stretch & Lambert, 1999). However within Study 2, the medium-fast bowlers performed at a lower physiological intensity as demonstrated by the shorter amount of time spent within HR Zones 2 and 3 (73 ± 27%). Therefore, it
seems plausible to suggest that BZ provides a stimulus similar to other training protocols and/or simulated match bowling protocols with the exception of CW simulations. Furthermore, while limited research has reported on the [BLa] responses of cricket match-play, several studies have reported on fast bowling simulation protocols (Burnett et al., 1995; Duffield et al., 2009). These previous studies have suggested that due to the intermittent nature of medium-fast bowling, anaerobic metabolism has a limited role in the energy demands of these players. Collectively, the [BLa] of medium-fast bowlers in the current study further suggests that the contribution of anaerobic metabolism is limited during a BZ bowling spell. Interestingly, the RPE for medium-fast bowlers represented a rating of ‘hard’ (5.2 ± 1.2), which was less than that which has previously been reported in CW match-simulations (4.5 ± 1.5). The greater RPE scores reported by Duffield et al. (2009) (6.5 ± 0.8) compared to the current study (5.2 ± 1.2), may reflect the greater number of overs performed by participants and the inclusion of scheduled LI activity between overs. Given that there is no available match-specific RPE data available for cricket match-play, it is unknown if the lower RPE values recorded during BZ replicated the perceived intensity of a match. When compared to the data of Study 2, medium-fast bowlers perceived generic BZ training to be more intense than CW simulation (BZ: 5.2 ± 1.2; CW simulation: 4.5 ± 1.5). Therefore, similar to the batsmen within the current study, medium-fast bowlers perform at a greater physiological intensity than that reported during CW simulations.
It has been shown that medium-fast bowlers cover the greatest distance during a cricket match (Petersen et al., 2010), however this was not demonstrated for BZ in the current study. The total distance covered is likely to be contingent on the number of overs completed; which may explain the contradictory results evident in the BZ session. However, this may well be justified, as a BZ session provides medium-fast bowlers a realistic training stimulus that provides a lower external TL, which may positively help in balancing load monitoring and restricting overuse injuries. Despite the differences in competition standards, the medium-fast bowlers covered a similar relative distance at both low- and HI’s in each BZ bout, but a much lower absolute distance due to fewer overs bowled when compared to the match data of Petersen et al. (2010). Also, the medium-fast bowlers of Study 2 covered a similar distance (3854 ± 795 m·h⁻¹) than that of the medium-fast bowlers in the current study (3637 ± 825 m·h⁻¹). This data suggests that while similar to the match demands of medium-fast bowlers, BZ may not provide as high a level of physical intensity in comparison to match-play.

**Spin Bowlers**

The current data demonstrates that spin bowlers spent the majority (~68%) of each BZ bout working at a physiological intensity between 51-85%HRₘₐₓ. This was similar to the demands of spin bowlers within Study 2 during CW practice (70 ± 37%). Spin bowlers also presented the lowest [BLa⁻], despite reporting the highest RPE scores. Due to the limited data that exists on the physiological demands of spin bowlers during a match, it is difficult to compare this with the results of the current study. However, Petersen et al. (2010) has previously
demonstrated that spin bowlers maintain a $HR_{\text{mean}}$ of approximately 135 b·min$^{-1}$ during a T20 match. This suggests that spin bowlers perform at a low to moderate intensity during both a BZ session and T20 match. This is further supported by the time spent within a lower HR zone during different training methods (shown in Study 2).

The total distance travelled by spin bowlers was considerably less than that of the batsmen (30%) and medium-fast bowlers (17%), which corresponded to a lower mean speed as well. Furthermore, the recovery time of spin bowlers between each HI effort was significantly longer than that of batsmen (27%). In comparison to match demands (Petersen et al., 2010), the spin bowlers in the current study demonstrated a similar ratio of low- and HI activities, despite a relatively smaller overall distance being completed. Furthermore, regardless of the training method used, spin bowlers completed a similar HI running distance (>3.5 m·s$^{-1}$) (BZ: 224 ± 112 m·h$^{-1}$; CW simulation: 262 ± 141 m·h$^{-1}$) with little difference in the time spent recovering between each HI effort also (BZ: 84 ± 42 s; CW simulation: 79 ± 47 s). When compared to other playing positions, the results of the current study also suggest that spin bowlers are less likely to perform extended periods of HI activity. However, given that only one spin bowler was used per BZ session, a greater sample size is necessary to make such conclusions.

**Fielders**

In the current study, fielders demonstrated a lower HR response when compared to other playing positions, with 74 ± 26% of the time spent within HR
Zone 2. Fielders spent a similar amount of time performing within Zone 2 as Study 2 during CW practice (74 ± 25%), suggesting a similar HR response can be gained through the use of either training method. Additionally, the amount of time spent at intensities above 85%HR_{max} was around 14% of the total time, with the fielders typically reaching only 78% of their HR_{max}. Based on this evidence, fielders appear to maintain low to moderate intensities during BZ, which is similar to previously reported T20 match data from Petersen et al. (2010). This data demonstrated that fielders maintained considerably lower HR_{mean} and HR_{max} than other playing positions.

Furthermore, fielders spent the majority of time performing LI movements (~82%), maintained a considerably lower mean speed and covered significantly less distance within each movement category when compared to batsmen. Fielders also received a longer recovery time between HI work periods, again most notably compared to that of batsmen, reiterating that fielding during a generic BZ scenario results in a moderate physiological stimulus suitable for training purposes. This is evident when compared to Petersen et al. (2010), who demonstrated fielders completed a higher percentage of LI efforts, and maintained a subsequent slower mean speed during a OD match. Further to this, these same fielders also received greater recovery time between HI efforts during a match in comparison to those during BZ. The greater physical demand of BZ amongst fielders is further highlighted when compared to that of fielders within Study 2. While a similar relative distance was covered by fielders during both training formats, fielders covered considerably greater HI distance during BZ than CW simulation (BZ: 426 ± 356 m·h^{-1}; CW simulation: 219 ± 117 m·h^{-1}).
This was most likely due to the greater number of HI efforts performed by fielders during BZ (63 ± 50 h⁻¹) coupled with less recovery time between each effort (54 ± 49 s). As a result, the use of BZ in place of the game-based training formats historically used may be more appropriate to provide fielders a match-specific physical load.

**Wicketkeepers**

In the current study, wicketkeepers spent a greater amount of time within HR Zone 2 (76 ± 30%) compared to any other playing position. Similar to fielders, only ~10% of time was spent at a high physiological intensities (>75%HRmax). The same trend was also observed during CW simulations in Study 2, however a considerably greater amount of time was spent within HR Zone 2 (93 ± 8%) when compared to the current data. Unsurprisingly, wicketkeepers recorded the lowest mean speed of all playing positions, combined with the greatest total distance covered at a LI. Given the role of a wicketkeeper is to maintain a relatively sedentary position behind the stumps, this skewed proportion within low HR zones and performing LI activities validly reflect the physiological and physical demands of the position (Petersen et al., 2010). Further evidence for the lower physiological demand of wicketkeepers is the largest work-to-recovery ratio of all the playing positions. However, it’s possible that the results of the current study may have been influenced by the BZ protocol itself. As wicketkeepers were not required to change ends following each over, the amount of time remaining stationary would have increased, hence may not reflect the match-based demands of such a position. This also may have led to the lesser physical demand placed upon wicketkeepers during BZ when
compared to that of CW simulations (Study 2). Furthermore, it is possible that wicketkeepers may have other physically taxing stationary roles that are not quantified by GPS monitoring.

Reproducibility of BZ

Previous research reporting on soccer SSG has put forward that selected physiological and physical responses are replicable both within and between training sessions, most notably during the smaller formats (Hill-Haas et al., 2008b; Rampinini et al., 2007). Accordingly, the secondary aim of the current study was to determine the reliability of BZ sessions within respective positions. Across each playing position (excluding spin bowlers due to a smaller sample size), no significant differences existed in any of the physiological or physical measures when comparing the two BZ sessions. Specifically, measures such as %HR\textsubscript{max} achieved and total distance spent in specific movement categories (with the exception of striding distance) were not significantly different between sessions. Remarkably, the mean speed and total distance covered by all participants were very similar between sessions, as reflected by the low CV and high ICC values (Table 5.4). However, both [BLa'] (mean CV: 46%) and RPE (23%) reported higher variability between sessions for batsmen and medium-fast bowlers. The number of HI efforts completed per bout was the most variable measure reported regardless of playing position, which may be due to factors such as placement of the ball by bowlers and batsmen during play. Unlike previous studies that have reported poor to moderate levels of reproducibility when using SSG as a training method (Hill-Haas et al., 2008b; Rampinini et al., 2007), the current data is reporting on a skill-based sport such
as cricket and has demonstrated that the variability between BZ sessions is reduced. This finding supports the observation of Petersen et al. (2010) where total distance covered during a cricket match was one of the least variable measures, and the number of sprints completed was one of the most variable. However, unlike Petersen et al. (2010) the movement demands were not always less variable than the physiological responses. Regardless, the use of BZ as part of cricket training or research design may be appropriate given the acceptable level of variability between respective sessions for physiological responses and movement demands.

Conclusion

The intended use of BZ was to employ a SSG format for cricket that targeted the technical and tactical abilities of cricket players within a match-intensive training environment. However, prior to this study it was unclear as to what external load and/or physiological responses were provided by BZ, and whether such responses were reliable between sessions. Previously, game-based training methods (Study 2) have demonstrated that they place lower physical and physiological training demands on players when compared to that of a typical OD cricket match. Therefore, there was a strong need for a specific training method that provided a match-appropriate TL for all cricket players, regardless of position to be developed. The main finding of the current study was that the intensity and physical demands of generic BZ sessions were typically representative of moderate to higher intensities, particularly for batsmen and medium-fast bowlers, and to a lesser extent, for spin bowlers, fielders and wicketkeepers. Such responses are highly comparable to previous
match data and training protocols of elite cricket players (Petersen et al., 2010; Petersen et al., 2011a), although further direct comparison of such data is required. Additionally, the results of the current study also suggest that the use of generic BZ sessions may be more appropriate at providing a greater match-specific TL than that of game-based CW simulations, particularly amongst batsmen. It also appears that the generic version of BZ demonstrated acceptable reliability between sessions. Based on this evidence, a consistent and effective training stimulus can be provided across all playing positions using a generic BZ scenario. As the technical nature of BZ remains unknown, TCT should be implemented to compliment BZ.

Practical Applications

- Unlike the historically game-based training employed in cricket (CW simulations), the use of generic BZ training is sufficient at providing cricket players across each playing position with a physiological and physical stimulus replicable of an actual OD match.
- Batsmen and medium-fast bowlers appear to gain the greatest training response from the use of generic BZ training due to the increased movement demands associated with this training format.
- Coaching staff can be confident that players will receive a consistent training stimulus through the use of generic BZ sessions due to the acceptable levels of reliability and variability of specific measures of training intensity and load.
Chapter 6

Study 4

Physiological, physical and technical demands of Battlezone, traditional net-based training and One-Day cricket matches: A comparative study of sub-elite cricket players.

As per the peer-reviewed paper Accepted and Published in the Journal of Sports Sciences:

Abstract

This study compared the physiological, physical and technical demands of BZ, TCT and OD matches. Data was initially collected from 11 amateur, male cricket players (age: 22.2 ± 3.3 yr, height: 1.82 ± 0.06 m, body mass: 80.4 ± 9.8 kg) during four BZ and four TCT sessions across the range of playing positions. Heart rate, [BLa], RPE and movement patterns of players were measured. Retrospective video analysis was performed to code for technical outcomes of each session. Similar data was collected from 42 amateur (which included the original cohort), male cricket players (23.5 ± 4.7 yr, 1.81 ± 0.07 m, 81.4 ± 11.4 kg) during ten OD matches. Significant differences (p < 0.05) were apparent in several physiological, physical and technical demands between BZ, TCT and OD matches within each playing position. Battlezone evoked the greatest physiological and physical demands from batsmen when compared to both TCT and OD matches. Specifically, batsmen performed with a greater HR_{mean} (164 ± 12 b min^{-1}) during BZ, which is likely due to the greater HI relative distance (1235 ± 422 m h^{-1}). However, the greatest technical demand (# balls faced: 303 ± 26 balls h^{-1}, # balls hit: 248 ± 34 balls h^{-1}, % good contact shots: 82 ± 7%) was observed for batsmen during the TCT. In regards to the other playing positions, greater physiological, physical and technical demands were observed during BZ and TCT when compared to that of the OD matches. Overall, a greater HR_{mean} was reported during BZ in comparison to TCT and OD matches regardless of playing position. The considerable greater relative distance covered at a HI, combined with a shorter recovery time between HI efforts is the likely cause of the increased physiological demand within medium-fast bowlers, spin bowlers, fielders and wicketkeepers. These results suggest that both BZ and TCT
training methods provide players with a suitable training stimulus for replicating the physiological, physical and technical demands of OD cricket. However, the use of BZ ensures a match-specific environment is facilitated which may increase the transference of skill and tactics during physiological load.

**Introduction**

Principles of training specificity suggest that training demands should replicate match requirements to ensure optimal adaptation (Reilly et al., 2009). Further to this, progressive training stress must be applied to achieve a continued adaptation and improvement in sports performance (Gamble, 2009). To assist with TL prescription, improvements in technology have allowed for the comparison of movement and physiological demands between training and match-play in an array of sports (Dawson et al., 2004; Gabbett, Jenkins & Abernethy, 2012b; Hartwig, Naughton & Searl, 2011; Spencer et al., 2004). Only recently has the measurement of movement demands been applied to cricket (Petersen et al., 2010; 2011b). As such, little information exists detailing comparative training and match demands of cricket players. Traditionally, the majority of cricket training has relied upon net-based activities (Pyke & Davis, 2010). As reported within Study 2, the use of game-based training in the form of CW practice has been a historically used method in an effort to provide players with a match-like training environment. However, it has been demonstrated that this form of training provided little similarity to the intensity of a competitive cricket match. The recent introduction of BZ has provided a field-based training method specific for cricket that is subject to various constraints in order to
provide a suitable alternative to net-based training (Renshaw et al., 2010) and game-based simulations (Study 2).

At present, only Petersen et al. (2011a) have quantified the demands of a TCT session. Training sessions are typically classified as either game simulations or skills sessions, which included net-based training and fielding drills. As stated by Petersen et al. (2011a), game simulations allowed players to practice during simulated match conditions, whereas skill sessions are solely designed to practice isolated technical skills (e.g. net bowling, net batting, boundary fielding). Interestingly, similar relative distances and mean and peak HR values were reported between the two types of training methods, despite the differences in duration and objectives of the sessions. However, Petersen et al. (2011a) also demonstrated the physiological demands of players were typically lower during game simulations and skill sessions when compared to match-play. Unfortunately, no comparison of the technical characteristics between respective versions of cricket training has been performed.

Although typically focusing on football-based team sports, past research has suggested that SSG allow players to simultaneously develop decision-making and technical abilities, whilst being placed under metabolic conditioning that is similar to match conditions (Dellal et al., 2008; Gabbett, 2006; Gamble, 2004). In the game of cricket, despite the prolonged physical requirement necessary for the sport, a greater emphasis is placed on developing technical proficiencies (Renshaw et al., 2010). Initial research suggests that the physical and physiological demands of this training method may be similar to that
experienced during a typical cricket match (Study 3). However, it is unclear if BZ provides cricket players with a greater physical, physiological or technical load in comparison to a more traditional net-based cricket training session. Furthermore, it remains unknown if these TL measures reflect the demands required throughout a typical OD cricket match. Additionally, no research has quantified the individual responses of amateur cricket players within traditional training and match-play settings. Previous research in FBTS has reported that the physiological, physical and technical responses of elite and amateur athletes can differ during similar training sessions and protocols (Dellal et al., 2011b; Sharhidd Taliep et al., 2008; Vaz, Leite, João, Gonçalves & Sampaio, 2012). As such, the purpose of this study was to compare the physiological responses, physical and technical demands between generic BZ sessions, traditional net-based training sessions and competitive OD cricket matches within amateur cricket players.

**Methods**

**Participants**

Initially, 11 male, amateur cricket players (age: 22.2 ± 3.3 yr, height: 1.82 ± 0.06 m, body mass: 80.4 ± 9.8 kg) volunteered to complete four repeat BZ and TCT sessions. Separately, 42 male, amateur cricket players (age: 23.5 ± 4.7 yr, height: 1.81 ± 0.07 m, body mass: 81.4 ± 11.4 kg) including the training subsample (n = 11) listed above, participated in ten OD matches. Participants were first grade players in a district standard cricket competition, and performed two cricket-specific training sessions per week. Participants were classified either as a batsman, medium-fast bowler, spin bowler, fielder or wicketkeeper.
according to their role during each bout. Participants gave verbal and written informed consent (see Appendix C) prior to any testing. The research was approved by the University of Newcastle Human Research Ethics Committee (H-2010-1288) (see Appendix D).

**Procedures**

The cohort of 11 participants completed a total of four BZ sessions and TCT sessions that were randomly assigned during the late pre-season period. Prior to each training session, participants completed a standardised 15 min warm-up that included LI running, dynamic stretches and cricket skill-based exercises. A BZ scenario similar to that presented in Study 3 was used for all BZ sessions. Each BZ session consisted of six repeat bouts of 6 overs on a cricket pitch surrounded by a 0.8 m high cricket net on the 30 yd (27.4 m) inner circle of a standard cricket field. One bout of BZ required two bowlers to complete three alternating overs to a batting pair, with the remaining participants placed at specific positions on the BZ field (as in Study 3). All participants performed as they would during a typical OD cricket match, with normal cricket rules and regulations (International Cricket Council, 2009) being applied to each session. Due to time constraints, each bout consisted of 6 overs (36 overs in total) rather than previously used 8 overs (Study 3) and each respective bout lasted 14 ± 3 min.

The TCT sessions were separated into two separate components including both net sessions and fielding drills. The net sessions consisted of two batsmen batting for 15 ± 1 min in separate nets whilst a total of 6 bowlers (3 in each net)
bowled continuously during the 15 min bout. All players were instructed to bat or bowl, respectively, as they would in a typical cricket match and this procedure was followed until each participant had completed the required batting bout. During each bout, those participants who were not required to bat or bowl rested outside the playing area. To ensure consistency between each training session and the different training modalities, the same batting and bowling order was used during each training session. Upon completion of the net session, all participants completed fielding drills (21 ± 3 min), which included low and high catching drills, and in-field and boundary ground fielding drills.

The data collected during both the BZ and the TCT sessions were compared to 50-over (n = 10) OD cricket matches. The rules and regulations of these OD matches followed those as outlined by the International Cricket Council (2009). The duration of each match was categorised by playing position: batsmen: 52 ± 22 min, medium-fast bowlers: 173 ± 40 min, spin-bowlers: 175 ± 36 min, fielders: 155 ± 38 min, and wicketkeepers: 176 ± 32 min.

**Physiological Measures**

A Polar Team² System (Polar Electro Oy, Kempele, Finland) measured (at 5 s intervals) HR throughout each training session and match. Each individual’s $HR_{\text{max}}$ was determined from the HR achieved prior to exhaustion from the performance of a Yo-Yo Intermittent Recovery Test Level 1 that was completed prior to the commencement of testing sessions. As previously reported in Studies 2 and 3, five separate HR zones were used to classify intensity: Zone 1 (0-50% $HR_{\text{max}}$), Zone 2 (51-75% $HR_{\text{max}}$), Zone 3 (76-85% $HR_{\text{max}}$), Zone 4 (86-
95% HR_{max}) and Zone 5 (>95% HR_{max}). The time spent (absolute and percentage of total time) within each of the HR zones during each training session and match was calculated using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia).

Capillary blood samples (5 µl) were obtained from a hyperaemic earlobe of each batsmen and bowler within 3 min of leaving the playing area after a 6-over or 15 min net session bout. Samples were immediately analysed for blood lactate (Lactate Scout, EKF Diagnostics, Magdeburg, Germany). During each match, the [BLa^-] of players was not measured during a cricket match due to the limited access to players. Following each BZ and TCT session, as well as upon completion of each innings of each match; batsmen and bowlers provided RPE using the CR-10 scale (Borg et al., 1987). Training load was then calculated using the session-RPE method by multiplying each player’s RPE (CR-10) by the duration (min) of each training session or match (Foster et al., 1995).

**Time-Motion Characteristics**

The movement patterns of each player during all training sessions and matches were recorded via MinimaxX GPS devices (v6.65, Catapult Innovations, Melbourne, Australia) sampling at a frequency of 10 Hz. Each GPS unit was situated between the shoulder blades of each participant using a specially designed harness (GPSports, Canberra, Australia). As instructed by the manufacturer, each GPS unit was turned on 15 min prior to player’s entering the playing area to ensure a satellite lock was established. As per Petersen et al. (2010) the following speed zones were used as categories for further analyses:
standing/walking (0-2.00 m·s⁻¹), jogging (2.01-3.50 m·s⁻¹), running (3.51-4.00 m·s⁻¹), striding (4.01-5.00 m·s⁻¹) and sprinting (>5.01 m·s⁻¹). Further to this, work-to-recovery ratio was defined as the ratio of time spent completing high-(running, striding, sprinting) to LI (standing/walking, jogging) activity (Petersen et al., 2010). Data was downloaded to determine movement characteristics of each participant following each session and match using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia). Data was then reported as per hour to standardise between sessions of different durations (Petersen et al., 2010). To ensure consistency between training sessions and match-play, the starting point of each bout was classified as the initial increase in velocity of the bowler delivering the initial delivery, and was completed when no increase in velocity was observed following the final delivery/dismissal using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia).

**Technical Skills**

Each BZ and TCT session was filmed using two fixed video cameras (HDV 1080i/mini DV Handycam, Sony, Japan) which were time aligned for analysis by synchronising the initial balled bowled during each testing session. One was positioned on the cricket pitch behind the stumps at the end each ball was delivered from. The second was placed perpendicular to the pitch outside the BZ playing area directly in line with the middle of the pitch, at a distance that enabled the entire playing area to be in view of the camera. During match-play only one camera, placed perpendicular to the pitch outside the playing area was used. The use of only one camera is acknowledged as a limitation in the accuracy of coding some of the technical outcomes, particularly the batsmen.
However, due to logistical considerations the use of a second camera behind the stumps during actual match-play was not feasible.

The video was retrospectively analysed after each training session and match to examine the technical characteristics of each playing position. Specifically, the number of deliveries faced and hit by batsmen were tallied, along with the number of times dismissed and chances provided. During BZ and OD matches, chances were defined as a missed opportunity for dismissing a batsman by an opposing player. For example, this may have represented a dropped catch or a missed stumping/run-out. As no fielders were present during TCT only dropped catches from bowlers (with no assistance from the surrounding nets) and edges hit directly behind the batsmen were considered a chance. Batting performance was assessed by classifying bat-ball contact as “good”, “bad” or “no” contact, with “no” being separated into “dot balls” and “play/miss” (Houghton et al., 2011a; Muller & Abernethy, 2008). The number of balls bowled by fast- and spin-bowlers was also recorded. Further to this, the number of throws completed by each player when fielding was counted.

**Statistical Analysis**

All data were reported as mean ± SD. As not all players were involved in each 6-over bout or 15 min net session, any data recorded whilst a player was not directly involved in each bout was not included in analyses. Data recorded during breaks in play during a match (e.g. drinks break) were also not considered for analysis. Using a customised spreadsheet developed by Hopkins (2003) effect sizes (Cohen’s $d$) (Cohen, 1988) (small = 0.2-0.49, moderate =
0.5-0.79, large = ≥0.8) were used to quantify the magnitude of difference of the physiological, physical and technical measures within each playing format between the different formats.

Results

Batsmen
The physiological and perceptual responses of batsmen during both training formats and OD matches are displayed in Table 6.1 (over the page). A large effect existed for peak \( %HR_{\text{max}} \) achieved during OD matches compared to BZ \((d = 0.88)\) and TCT \((d = 1.31)\). Similarly, the greatest \( HR_{\text{mean}} \) resulted from BZ compared to TCT \((d = 0.81)\) and OD matches \((d = 0.45)\), which reflected a greater percentage of time spent in HR Zone 4 and less in Zone 3. There was also a large effect \((d = 1.15)\) for higher \([\text{BLA}^-]\) during BZ training than TCT. Greater RPE and TL measures were reported following BZ with moderate effects \((d = 0.59\) and 0.67) when compared to TCT, and small effects \((d = 0.22\) and 0.23) against OD matches.
Table 6.1: Comparison of the physiological and perceptual responses by position during Battlezone, traditional cricket training and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Physiological and Perceptual Responses</th>
<th>Batsman</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak %HR&lt;sub&gt;max&lt;/sub&gt;</td>
<td>BZ (n=46)</td>
<td>TCT (n=45)</td>
<td>OD (n=16)</td>
<td>BZ (n=28)</td>
<td>TCT (n=36)</td>
</tr>
<tr>
<td>HR&lt;sub&gt;mean&lt;/sub&gt; (b·min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>164 ± 12</td>
<td>153 ± 15&lt;sup&gt;§&lt;/sup&gt;</td>
<td>159 ± 12&lt;sup&gt;¶&lt;/sup&gt;</td>
<td>152 ± 32</td>
<td>147 ± 31</td>
</tr>
<tr>
<td>HR Zones (% of Time)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>3 ± 8</td>
<td>5 ± 16</td>
<td>4 ± 7</td>
<td>2 ± 7</td>
<td>8 ± 20&lt;sup&gt;†&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>16 ± 18</td>
<td>36 ± 37&lt;sup&gt;§&lt;/sup&gt;</td>
<td>23 ± 19&lt;sup&gt;¶&lt;/sup&gt;</td>
<td>29 ± 16</td>
<td>37 ± 34&lt;sup&gt;†&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>33 ± 18</td>
<td>38 ± 30&lt;sup&gt;†&lt;/sup&gt;</td>
<td>39 ± 12&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>39 ± 9</td>
<td>31 ± 26&lt;sup&gt;†&lt;/sup&gt;</td>
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<tr>
<td>4</td>
<td>40 ± 24</td>
<td>18 ± 26&lt;sup&gt;§&lt;/sup&gt;</td>
<td>29 ± 17&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>26 ± 16</td>
<td>21 ± 28&lt;sup&gt;†&lt;/sup&gt;</td>
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<tr>
<td>5</td>
<td>5 ± 9</td>
<td>1 ± 4&lt;sup&gt;§&lt;/sup&gt;</td>
<td>4 ± 5&lt;sup&gt;¶&lt;/sup&gt;</td>
<td>2 ± 3</td>
<td>2 ± 5</td>
</tr>
<tr>
<td>[BLa&lt;sub&gt;1&lt;/sub&gt;] (mmol·L&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>3.2 ± 1.4</td>
<td>1.8 ± 1.0&lt;sup&gt;§&lt;/sup&gt;</td>
<td>2.7 ± 1.5&lt;sup&gt;†&lt;/sup&gt;</td>
<td>2.7 ± 1.5</td>
<td>1.8 ± 0.6&lt;sup&gt;§&lt;/sup&gt;</td>
</tr>
<tr>
<td>RPE (AU)</td>
<td>5.3 ± 1.5</td>
<td>4.5 ± 0.9&lt;sup&gt;†&lt;/sup&gt;</td>
<td>6.2 ± 1.4&lt;sup&gt;†&lt;/sup&gt;</td>
<td>6.2 ± 1.4</td>
<td>5.2 ± 0.7&lt;sup&gt;§&lt;/sup&gt;</td>
</tr>
<tr>
<td>Training Load (AU·hr&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>318 ± 90</td>
<td>261 ± 81&lt;sup&gt;†&lt;/sup&gt;</td>
<td>371 ± 83&lt;sup&gt;†&lt;/sup&gt;</td>
<td>261 ± 81</td>
<td>312 ± 73&lt;sup&gt;§&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Difference in comparison to BZ (<sup>†</sup> small; <sup>‡</sup> moderate; <sup>§</sup> large); Difference in comparison to TCT (<sup>||</sup> small; <sup>¶</sup> moderate; <sup>Δ</sup> large).
The total distance covered and distance covered within each movement category was greatest during BZ as opposed to TCT \((d = 2.29 \pm 1.45)\) and OD matches \((d = 1.72 \pm 1.02)\). Further, relative measures of distances covered \((\text{m} \cdot \text{h}^{-1})\) were consistently different between the OD matches and TCT \((d = 2.21 \pm 0.72)\). As shown in Table 6.2 (over the page), mean speed was highest during BZ, when compared to both TCT \((d = 3.52)\) and OD matches \((d = 1.88)\). There were also large effects for the number of HI efforts and sprints each hour combined with a shorter work-to-recovery ratio, respectively; with each being higher in BZ than either TCT \((d = 3.76, 1.71 \text{ and } 1.25)\) or OD matches \((d = 3.24, 1.03 \text{ and } 1.15)\) (Table 6.3, page 154). Finally, the greatest technical demands, most notably the relative number of balls faced and hit by batsmen for batsmen occurred during TCT (Table 6.4, 154), which exceeded that reported for BZ \((d = 4.07 \pm 3.14)\) and OD matches \((d = 1.55 \pm 0.93)\) across all technical measures.

**Medium-Fast Bowlers**

As shown in Table 6.1, the lowest peak \%HR_{\text{max}} occurred during TCT with a large effect for greater peak \%HR_{\text{max}} during BZ \((d = 0.97)\) and OD matches \((d = 1.31)\). Only a small effect was present for HR_{\text{mean}}, with it being lower during OD matches when compared to BZ \((d = 0.44)\) and TCT \((d = 0.23)\). Various differences were present for the time spent across the different HR zones in the medium-fast bowlers. In addition, [BLa] was slightly higher during BZ than TCT \((d = 0.79)\). Measures of RPE and TL from OD matches were higher when compared to BZ \((d = 1.02 \text{ and } 1.09)\) and TCT \((d = 2.07 \text{ and } 2.12)\), respectively.
Table 6.2: Comparison of the total distances covered in each movement category across playing positions during Battlezone, traditional cricket training and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Measures of Movement</th>
<th>Batsman (n=46)</th>
<th>Medium-Fast Bowler (n=28)</th>
<th>Spin Bowler (n=12)</th>
<th>Fielder (n=32)</th>
<th>Wicketkeeper (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BZ</td>
<td>TCT</td>
<td>OD</td>
<td>BZ</td>
<td>TCT</td>
</tr>
<tr>
<td>Distance Covered</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m⁻¹) Walking</td>
<td>1428 ± 514</td>
<td>1214 ± 404</td>
<td>2588 ± 2403</td>
<td>2220 ± 1152</td>
<td>2338 ± 2191</td>
</tr>
<tr>
<td></td>
<td>457 ± 353</td>
<td>368 ± 120</td>
<td>468 ± 584</td>
<td>397 ± 142</td>
<td>269 ± 627</td>
</tr>
<tr>
<td></td>
<td>1190 ± 390</td>
<td>418 ± 500</td>
<td>1248 ± 725</td>
<td>707 ± 112</td>
<td>563 ± 877</td>
</tr>
<tr>
<td></td>
<td>809 ± 040</td>
<td>0 ± 296</td>
<td>1401 ± 513</td>
<td>650 ± 4</td>
<td>284 ± 358</td>
</tr>
<tr>
<td></td>
<td>406 ± 039</td>
<td>72 ± 33</td>
<td>311 ± 278</td>
<td>113 ± 42</td>
<td>71 ± 83</td>
</tr>
<tr>
<td></td>
<td>152 ± 022</td>
<td>134 ± 65</td>
<td>173 ± 137</td>
<td>54 ± 23</td>
<td>117 ± 71</td>
</tr>
<tr>
<td></td>
<td>636 ± 016</td>
<td>65 ± 4</td>
<td>218 ± 269</td>
<td>59 ± 9</td>
<td>127 ± 147</td>
</tr>
<tr>
<td></td>
<td>283 ± 012</td>
<td>64 ± 43</td>
<td>294 ± 320</td>
<td>158 ± 4</td>
<td>170 ± 98</td>
</tr>
<tr>
<td></td>
<td>193 ± 010</td>
<td>2 ± 11</td>
<td>333 ± 407</td>
<td>81 ± 3</td>
<td>73 ± 98</td>
</tr>
<tr>
<td>Total Distance</td>
<td>3895 ± 560</td>
<td>1919 ± 424</td>
<td>4970 ± 4299</td>
<td>3389 ± 312</td>
<td>3172 ± 3419</td>
</tr>
<tr>
<td></td>
<td>1236 ± 470</td>
<td>793 ± 121</td>
<td>1735 ± 1125</td>
<td>1038 ± 102</td>
<td>658 ± 951</td>
</tr>
<tr>
<td></td>
<td>2519 ± 552</td>
<td>1632 ± 94</td>
<td>3837 ± 3128</td>
<td>2927 ± 292</td>
<td>2900 ± 3196</td>
</tr>
<tr>
<td></td>
<td>1173 ± 452</td>
<td>749 ± 345</td>
<td>1437 ± 934</td>
<td>935 ± 93</td>
<td>500 ± 861</td>
</tr>
<tr>
<td></td>
<td>1235 ± 422</td>
<td>452 ± 152</td>
<td>1053 ± 1090</td>
<td>441 ± 261</td>
<td>261 ± 209</td>
</tr>
<tr>
<td></td>
<td>851 ± 139</td>
<td>1716 ± 126</td>
<td>1196 ± 1061</td>
<td>9530 ± 12</td>
<td>698 ± 904</td>
</tr>
<tr>
<td></td>
<td>222 ± 119</td>
<td>1315 ± 126</td>
<td>477 ± 272</td>
<td>2654 ± 12</td>
<td>477 ± 272</td>
</tr>
<tr>
<td></td>
<td>65 ± 21</td>
<td>9 ± 8</td>
<td>34 ± 17</td>
<td>54 ± 15</td>
<td>53 ± 11</td>
</tr>
<tr>
<td>Mean Speed (m min⁻¹)</td>
<td>93 ± 29</td>
<td>71 ± 19</td>
<td>54 ± 15</td>
<td>54 ± 15</td>
<td>66 ± 27</td>
</tr>
<tr>
<td></td>
<td>15 ± 12</td>
<td>28 ± 6</td>
<td>38 ± 12</td>
<td>43 ± 14</td>
<td>45 ± 14</td>
</tr>
</tbody>
</table>

Difference in comparison to BZ († small; § moderate; ¶ large); Difference in comparison to TCT (¶ small; † moderate; § large).
Table 6.3: Comparison of the movement characteristics by position during Battlezone, traditional cricket training and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Movement Characteristics</th>
<th>Batsman</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BZ (n=46)</td>
<td>TCT (n=45)</td>
<td>OD (n=16)</td>
<td>BZ (n=28)</td>
<td>TCT (n=36)</td>
</tr>
<tr>
<td>High-Intensity Efforts (# h⁻¹)</td>
<td>224 ± 73</td>
<td>10 ± 34&lt;sup&gt;§&lt;/sup&gt;</td>
<td>50 ± 21&lt;sup&gt;†&lt;/sup&gt;</td>
<td>184 ± 61</td>
<td>219 ± 59&lt;sup&gt;△&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sprints (# h⁻¹)</td>
<td>23 ± 19</td>
<td>0 ± 1&lt;sup&gt;§&lt;/sup&gt;</td>
<td>8 ± 8&lt;sup&gt;△&lt;/sup&gt;</td>
<td>29 ± 29</td>
<td>32 ± 39</td>
</tr>
<tr>
<td>Mean Sprint Distance (m)</td>
<td>8 ± 4</td>
<td>0 ± 2&lt;sup&gt;§&lt;/sup&gt;</td>
<td>9 ± 4&lt;sup&gt;△&lt;/sup&gt;</td>
<td>7 ± 5</td>
<td>5 ± 5&lt;sup&gt;†&lt;/sup&gt;</td>
</tr>
<tr>
<td>Maximal Speed (m s⁻¹)</td>
<td>5.8 ± 1.0</td>
<td>1.9 ± 1.5&lt;sup&gt;†&lt;/sup&gt;</td>
<td>6.5 ± 1.2&lt;sup&gt;△&lt;/sup&gt;</td>
<td>5.7 ± 1.2</td>
<td>5.2 ± 1.0&lt;sup&gt;△&lt;/sup&gt;</td>
</tr>
<tr>
<td>Work-to-Recovery Ratio (1:x)</td>
<td>13 ± 7</td>
<td>779 ± 865&lt;sup&gt;△&lt;/sup&gt;</td>
<td>66 ± 65&lt;sup&gt;§&lt;/sup&gt;</td>
<td>23 ± 31</td>
<td>21 ± 33</td>
</tr>
</tbody>
</table>

Difference in comparison to BZ († small; □ moderate; § large); Difference in comparison to TCT († small; □ moderate; ‡ large).
Table 6.4: Comparison of the technical characteristics of batsmen during Battlezone, traditional cricket training and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Technical Characteristics</th>
<th>BZ (n=46)</th>
<th>TCT (n=45)</th>
<th>OD (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balls Faced ( #h⁻¹)</td>
<td>82 ± 18</td>
<td>303 ± 26$^g$</td>
<td>47 ± 9$^§a$</td>
</tr>
<tr>
<td>Balls Hit ( #h⁻¹)</td>
<td>66 ± 17</td>
<td>248 ± 34$^g$</td>
<td>33 ± 6$^§a$</td>
</tr>
<tr>
<td>Dot Balls ( #h⁻¹)</td>
<td>17 ± 10</td>
<td>120 ± 29$^g$</td>
<td>33 ± 8$^§a$</td>
</tr>
<tr>
<td>Play-Miss ( #h⁻¹)</td>
<td>14 ± 8</td>
<td>37 ± 17$^g$</td>
<td>7 ± 3$^§a$</td>
</tr>
<tr>
<td>Defensive Shots ( #h⁻¹)</td>
<td>7 ± 6</td>
<td>76 ± 23$^g$</td>
<td>12 ± 5$^§a$</td>
</tr>
<tr>
<td>Attacking Shots ( #h⁻¹)</td>
<td>57 ± 19</td>
<td>172 ± 39$^g$</td>
<td>21 ± 4$^§a$</td>
</tr>
<tr>
<td>Times Dismissed ( #h⁻¹)</td>
<td>2 ± 3</td>
<td>1 ± 1$^†$</td>
<td>1 ± 1$^†$</td>
</tr>
<tr>
<td>Chances ( #h⁻¹)</td>
<td>2 ± 3</td>
<td>8 ± 7$^g$</td>
<td>1 ± 1$^†$ $^Δ$</td>
</tr>
<tr>
<td>% Good Contact Shots</td>
<td>81 ± 12</td>
<td>82 ± 7</td>
<td>75 ± 8$^g$ $^Δ$</td>
</tr>
</tbody>
</table>

Difference in comparison to BZ ( $^†$ small; $^‡$ moderate; $^§$ large); Difference in comparison to TCT ( $^†$ small; $^‡$ moderate; $^§$ large).

Similar total relative distances within each movement category were reported between BZ and TCT (Table 6.2, $d = 0.31 ± 0.20$). However, both training formats required greater relative distances to be covered within each movement category than OD matches ($d = 1.13 ± 0.57$ and $0.90 ± 0.75$, respectively).

Again, BZ demonstrated the fastest mean speed when compared to both TCT ($d = 0.90$) and OD matches ($d = 1.69$). Similar movement characteristics were completed during BZ and TCT ($d = 0.32 ± 0.23$) as shown in Table 6.3. Fewer HI activities and sprints were performed during OD matches than BZ ($d = 2.72$ and $0.81$) and TCT ($d = 3.62$ and $0.72$), respectively. The total number of balls bowled was greatest during OD matches (Table 6.5, page 157) compared to BZ ($d = 3.71$) and TCT ($d = 2.98$). However, when relative to time (m.h⁻¹), there was a large effect for more balls to be delivered during TCT than either BZ ($d = 0.98$) or OD matches ($d = 8.54$).
Spin Bowlers

The peak %HR<sub>max</sub> during OD matches was considerably higher than both BZ (<i>d</i> = 1.23) and TCT (<i>d</i> = 0.94). As previously shown in Table 6.1, the lowest HR<sub>mean</sub> was reported during OD matches, with a large effect demonstrated with both BZ (<i>d</i> = 1.25) and TCT (<i>d</i> = 1.63). The percentage of time spent within each HR zone differed consistently between the training formats and matches. There was a large effect (<i>d</i> = 0.95) for a greater [BLat] in BZ than TCT, but not the OD matches. Greater RPE and TL measures were reported following TCT, which were demonstrated to be smaller to moderately greater than that reported following BZ (<i>d</i> = 0.71 and 0.69) and OD matches (<i>d</i> = 0.22 and 0.25).

The relative distances covered in each movement category during OD matches were lower than either BZ (<i>d</i> = 1.76 ± 0.97) or TCT (<i>d</i> = 1.53 ± 1.08). Further, TCT required slightly higher relative distances to be covered (<i>d</i> = 0.39 ± 0.28) than BZ. The greatest mean speed was reported during TCT (Table 6.2), compared to BZ (<i>d</i> = 0.87) and OD matches (<i>d</i> = 5.10). A greater number of HI activities were required during TCT when compared to BZ (<i>d</i> = 2.01) and OD matches (<i>d</i> = 3.41). The longest work-to-recovery ratio occurred during TCT, which was slightly increased compared to BZ (<i>d</i> = 0.60) and OD matches (<i>d</i> = 0.62) (Table 6.3). Considerably more balls were bowled each session during OD matches than BZ (<i>d</i> = 1.34) and TCT (<i>d</i> = 0.98).
Table 6.5: Comparison of the technical characteristics of medium-fast bowlers, spin bowlers, fielders and wicketkeepers during Battlezone, traditional cricket training and One-Day matches (mean ± SD).

<table>
<thead>
<tr>
<th>Technical Characteristics</th>
<th>Medium-Fast Bowler</th>
<th>Spin Bowler</th>
<th>Fielder</th>
<th>Wicketkeeper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BZ (n=28)</td>
<td>TCT (n=36)</td>
<td>OD (n=9)</td>
<td>BZ (n=12)</td>
</tr>
<tr>
<td>Total Balls Bowled (#)</td>
<td>18 ± 1</td>
<td>23 ± 3§</td>
<td>47 ± 11§a</td>
<td>18 ± 1</td>
</tr>
<tr>
<td>Balls Bowled (# h⁻¹)</td>
<td>78 ± 14</td>
<td>90 ± 11§</td>
<td>17 ± 5§a</td>
<td>85 ± 16</td>
</tr>
<tr>
<td>Total Throws (#)</td>
<td>2 ± 1</td>
<td>10 ± 3§</td>
<td>3 ± 2</td>
<td>7 ± 3</td>
</tr>
<tr>
<td>Throws (# h⁻¹)</td>
<td>9 ± 5</td>
<td>3 ± 1§</td>
<td>12 ± 9</td>
<td>30 ± 16</td>
</tr>
</tbody>
</table>

*Difference in comparison to BZ (§ small; ¶ moderate; § large); Difference in comparison to TCT († small; ¶ moderate; § large).*
Fielders

The greatest percentage of HR$_{\text{max}}$ reached was greatest during OD matches, when compared against either BZ ($d = 0.93$) and TCT ($d = 0.82$). Similar HR$_{\text{mean}}$ values were reported during BZ and TCT, with both training formats being higher than that reported for OD matches with a moderate ($d = 0.36$) and large ($d = 0.80$) effect being present. Small effects ($d = 0.36 \pm 0.08$) were reported for an increased HR response across the time spent in each HR zone between BZ and TCT sessions.

There was a large effect for greater total relative distance to be covered in BZ ($d = 1.09$) and TCT ($d = 1.36$) than in OD matches. Small effects were also reported for greater total relative distances covered in BZ ($d = 0.26$) than TCT. Slightly greater distance was covered at a LI during BZ than TCT ($d = 0.26$), although similar distances were covered at HI's (Table 6.2). Both BZ ($d = 0.95$ and 1.09) and TCT ($d = 1.07$ and 1.00) demonstrated large effects for greater relative distance to be covered at a LI and HI when compared to OD matches. Additionally, a greater number of HI efforts were performed during BZ ($d = 1.33$) and TCT ($d = 1.88$) than OD matches. A similar number of HI efforts were performed during BZ and TCT. Fewer throws, both overall and relative to time, were required during BZ ($d = 3.33$ and 1.46) and OD matches ($d = 2.42$ and 1.29) than TCT.
Wicketkeepers

One-Day matches elicited the highest \%HR_{\text{max}} in comparison to BZ \(d = 0.53\) and TCT \(d = 1.48\). There was a large effect for a higher HR_{\text{mean}} during BZ than TCT \(d = 0.95\) and OD matches \(d = 1.11\). Training formats also varied the time spent by wicketkeepers within the different HR zones as shown in Table 6.1.

Total distance covered was greatest during BZ \(d = 1.56\) and TCT \(d = 1.17\) when compared to the OD matches. Greater distances were also covered across jogging, running and striding speeds during BZ \(d = 0.89, 0.93\) and 1.65) and TCT \(d = 1.12, 1.02\) and 2.11), respectively, compared to OD matches. Mean speed was fastest during BZ (Table 6.2), when compared to both TCT \(d = 0.54\) and OD matches \(d = 1.58\). A greater number of HI activities were performed during TCT than BZ \(d = 1.41\) and OD matches \(d = 1.57\). The total number of throws relative to session duration was greatest during TCT (Table 6.5), with a large effect reported for greater throws compared to BZ \(d = 1.81\) and OD matches \(d = 3.33\).

Discussion

The aim of this study was to examine the physiological, physical and technical demands of different forms of cricket training, including BZ, TCT and OD matches. Similar to Studies 2 and 3, as well as Petersen et al. (2010), position specific differences were evident in the physical and physiological demands between the various training formats and match-play. Furthermore, in most instances, the relative physiological, physical and technical responses of
players during BZ or TCT sessions replicated or exceeded that observed for OD match-play in the amateur cohort. These results highlight that both BZ and TCT methods provide cricket players with a match-intensive and specific training environment, though the extent of this may be dependent on the playing position.

**Batsmen**

Previous research on the match demands of cricket batsmen suggests HR ranges between 139-154 b min\(^{-1}\) (Nicholson et al., 2009) and they cover a total distance of 2476 ± 720 m h\(^{-1}\) throughout a OD batting innings (Petersen et al., 2010). During BZ, batsman covered considerably more relative distance by comparison (3895 ± 1236 m h\(^{-1}\)) and performed at a greater physiological intensity (164 ± 12 b min\(^{-1}\)). The current findings demonstrate that when expressed relative to session duration, BZ provides batsmen with a greater physical and physiological TL than either TCT sessions or OD matches. With a large effect present for a greater time spent above 85%HR\(_{\text{max}}\) and HR\(_{\text{mean}}\), a greater physiological load was imposed on batsmen during BZ. This most likely results from the increased distances covered at higher velocities and a reduced work-to-recovery ratio. In contrast, the mean speed, total relative HI running and HR responses during TCT sessions failed to replicate that of a OD match. These decreased physical demands during TCT are explained by the reductions in the relative distances covered, particularly in HI activities. Furthermore, unlike TCT, where batsmen are limited to playing shots during the duration of the session with limited requirement to run, BZ also requires players to run between the wickets after playing a shot. This in turn, replicates the
movement demands of a match placing greater TL’s on batsmen that provides a match-intensive physical stimulus.

Alternatively, batsmen received more opportunity to develop their batting-specific skills in net-based environments, which reflects the increased skill repetition of this form of training. Notwithstanding, the quality of the shots played by batsmen (% of good contacts shots) in BZ was not affected by the smaller volume of technical skills performed. However, TCT was shown to demonstrate a greater number of chances (i.e. more dismissal opportunities) being provided by the batsmen compared to BZ and OD matches (Table 6.4). This is most likely explained by the absence of fielder pressure within the TCT session, allowing batsmen to place less emphasis on being dismissed, in contrast to a typical game setting. Therefore, it is possible that if the duration of each BZ bout was increased, batsmen would be exposed to a training stimulus that facilitates increases in technical performance, as well as realistic physical and physiological demands. As such, the BZ environment appears to replicate the relative physical demands experienced in a typical OD match.

**Medium-Fast Bowlers**

Past data has shown that medium-fast bowlers maintain a physiological intensity of approximately 135 b\(\text{min}^{-1}\) and cover a total relative distance of 3831 ± 839 m\(\text{h}^{-1}\) (Petersen et al., 2010). As with batsmen, BZ was performed at a greater physiological intensity than previous match data (152 ± 32 b\(\text{min}^{-1}\)), whilst covering more distance (4970 ± 1735 m\(\text{h}^{-1}\)). Within the medium-fast bowlers in the current study, small differences were observed in the HR
responses between BZ and TCT sessions. However, only small effects existed in the distances covered within each speed zone between BZ and TCT sessions, although medium-fast bowlers tended to cover a greater distance per hour and achieve a higher mean speed during BZ. In both training formats, the physiological and physical demands of medium-fast bowlers exceeded that reported for OD cricket matches, particularly the amount of time spent within 51-75%HR_{max}, the distance covered above 3.5 m·s\(^{-1}\) and the number of HI efforts performed. Interestingly, these data also exceeded the physiological and physical demands of elite and professional medium-fast bowlers (Petersen et al., 2010; Petersen et al., 2011b) during first class OD matches. Despite this greater TL, there was a large effect for greater perceptual responses of medium-fast bowlers following OD matches as opposed to training. The longer duration of a typical OD match may have contributed to the increase in perceived exertion and as such, imposed TL (Foster, Daines, Hector, Snyder & Welsh, 1996; Foster et al., 2001). Nevertheless, the results of the current study demonstrate that the physiological and physical stimuli provided to medium-fast bowlers is similar between BZ and TCT formats. Accordingly, either training method appears to provide a suitable match-simulated load when compared to a relative time-matched duration of a OD match.

An important element of training is to ensure sufficient skill repetition or practice (Helsen, Starkes & Hodges, 1998). When expressed as a whole training session (3 x 15 min net bowling bouts per session), the greatest number of balls was delivered during TCT sessions (69 ± 9) followed by an entire BZ session (3 x 15 min bouts/session; 54 ± 3 balls per session). This greatly exceeds the
average number of balls bowled during a typical OD match (47 ± 11). As with the physiological and physical demands of medium-fast bowlers during training, the technical demands of medium-fast bowlers during both training formats replicates or exceeds that required within a OD match. Taken together, this data demonstrates that medium-fast bowlers are provided with a sufficient TL from either BZ or TCT sessions.

**Spin-Bowlers**

Little information is available that quantifies the match demands of spin bowlers, with the only data being taken from Petersen et al. (2010) who reported that spin bowlers covered 3166 ± 536 m·h⁻¹ during a OD match which is similar to that covered by spin bowlers during a generic BZ session (3172 ± 658 m·h⁻¹). The current data demonstrates that spin bowlers maintained the highest physiological intensity (as per HRmean) throughout BZ training, which reflects a greater amount of time spent above 85% HRmax compared to both TCT and OD matches. Despite this greater physiological load of BZ, the perceptual responses were lower than those reported following TCT and OD matches. Surprisingly in the current study, the physical demands differed greatly across both BZ and TCT sessions to that of a OD match. In particular, spin bowlers demonstrated a higher mean speed during both TCT (61 ± 11 m·min⁻¹) and BZ (53 ± 11 m·min⁻¹). However, this reflects the greater number of HI efforts required in both BZ (40 ± 41 h⁻¹) and TCT (135 ± 53 h⁻¹) than match-play (7 ± 2 h⁻¹). Based on this evidence, it appears that both training formats provide spin bowlers a relative match-appropriate TL. Separately, spin bowlers delivered more balls bowled throughout both training sessions (BZ: 85 ± 16 # balls h⁻¹;
TCT: 88 ± 25 # balls h⁻¹) compared to OD matches (14 ± 10 # balls h⁻¹). Therefore, the volume of technical demand for spin bowlers was highest during either BZ or TCT, and it greatly exceeded that required during a OD match. However, as no extensive research has examined the technical skills of spin bowlers whilst training or competing, it remains unclear if this is a sufficient bowling load. Similar to Study 3, the small number of spin bowlers used in the current study presents a limitation in interpreting these results, and as such future research should increase the number of spin bowlers used.

Fielders

As with spin bowlers, limited information is available regarding the OD physical and physiological match demands of fielders. Only Petersen et al. (2010) has reported on the distances covered during a typical OD match (3081 ± 723 m h⁻¹), which is somewhat less than that covered during a BZ session (3977 ± 1598 m h⁻¹). In agreement, the current data demonstrates that a greater relative physical load was imposed on fielders during both BZ and TCT sessions than match-play. Surprisingly, the physiological responses and physical demands of fielding were similar during BZ and TCT, even though they were performed in an dichotic integrated or isolated fashion, respectively. Furthermore, in comparison to both BZ and TCT, fielders covered a significantly greater distance per hour than a OD match. This greater physical demand during training was reflected within the cardiovascular responses of the fielders, with a moderate effect for a greater amount of time spent performing above 75%HR_{max} in both training formats compared to matches. It is suggested that the BZ and TCT sessions in this current study provide fielders with a
physiological intensity that was suitable for training purposes as it replicated match intensity.

In regards to the number of throws performed by fielders, when expressed over the entire BZ session (3 x 15 min bouts), a greater number of throws were completed during BZ (21 ± 15) and TCT (17 ± 3) than OD matches (7 ± 5). A similar finding was reported by Saw et al. (2009), whereby a substantially greater number of throws were completed during fielding training (42 ± 26) compared to an actual match (10 ± 10). Therefore it appears that both training formats may allow fielders to perform skill-specific training that exceeds match demands, either in isolation or integrated into SSG environment.

**Wicketkeepers**

As noted within the other playing positions, a greater physiological response was typical of wicketkeepers in the current study (HR$_{\text{mean}}$: 154 ± 11 b·min$^{-1}$) as opposed to that reported previously (HR$_{\text{mean}}$: ~135 b·min$^{-1}$) (Petersen et al., 2010). However, wicketkeepers in the current study reported a similar physical demand to that which has previously been reported during OD matches (Study 4 total relative distance: 2685 ± 865 m·h$^{-1}$; Petersen et al. [2010]: 2711 ± 723 m·h$^{-1}$). When compared to OD matches, a large effect was present for the HR$_{\text{mean}}$ of wicketkeepers to be highest during BZ. It could be suggested this reflects the small effects demonstrated for the less time spent within HR Zone 2 and considerably more time in HR Zone 4 between the training and match formats. Consequently, this higher physiological load is reflective of the increased movement demands of the wicketkeeper during BZ. During both
training formats, wicketkeepers covered substantially more distance per hour than demonstrated for OD matches. Furthermore, greater relative distance was covered at HI’s during both the training formats, translating into a greater mean speed when compared to OD matches. In regards to the technical characteristics of wicketkeepers, both training formats required wicketkeepers to complete considerably more throws (when expressed for a full session for BZ) compared to OD matches. However as previously mentioned within Study 4, given that throwing is not typically a priority for wicketkeepers during a match, it may not be the most appropriate measure of skill and catching proficiency should be considered in future research.

**Conclusion**

This study quantified and compared the physiological, physical and technical demands of BZ, TCT methods and OD matches. Overall, it appears that across all playing positions, the physiological, physical and technical demands of BZ and TCT replicated or exceeded the relative demands of a OD match in amateur players. In particular, the loads imposed on batsmen during either BZ or TCT sessions exceeded that of a typical elite batsmen during a OD cricket match (Petersen et al., 2010). Further, similar match-appropriate loads were observed in either BZ or TCT by medium-fast bowlers, spin bowlers, fielders and wicketkeepers. However, due to the increased movement demands and physiological intensity of BZ training when compared to TCT, the former may prove more beneficial at developing the match-specific fitness of cricket players. As such, cricket coaches may want to consider the use of BZ more frequently in their training programs as it appears that this method provides a similar, and in
some cases, a greater TL to more TCT methods to exceed the relative demands of an actual OD cricket match. However, the results of this study also show that a superior technical demand comes from the use of more TCT methods compared to that of BZ and a typical OD cricket match for each playing position. Therefore, to allow for the concurrent development of a player’s conditioning status and technical ability and gain an appropriate TL, the periodised use of both BZ and TCT methods may be more beneficial than training method in isolation. The use of BZ however, is more likely to allow players to also gain a sense of match awareness due to the match-specific environment in which they can be placed.

Practical Applications

- Cricket players, regardless of playing position exhibit physical and physiological intensities that replicate match demands, using either BZ or TCT. However, players are more likely to exceed the physical and physiological demands of a typical OD match using the BZ training method due to the increased movement demands and shorter recovery time between HI activities.

- For the development of a player’s technical skill it appears that the use of TCT methods may be more beneficial within each of the different playing positions due to the greater volume of technical skill performed.

- When preparing cricket training programs with the aim of developing a player’s physical fitness level and technical ability, coaches should
consider using both BZ and TCT concurrently due to the advantages each different training format provides.

- The use of BZ provides the additional advantage of allowing players to develop match awareness skills and developing tactical game-skills due to the similarity to a typical match environment that is provided by the BZ method.
Chapter 7
Study 5

The influence of field size, player number and rule changes on the physiological responses and movement demands of small-sided games for cricket training.

As per the peer-reviewed paper Accepted and Published in the Journal of Sports Sciences:

Abstract

This study investigated the physiological responses and movement demands associated with modifications to the constraints of BZ. Eleven male, cricket players (22.2 ± 3.6 yr; 1.80 ± 0.06 m; 81.7 ± 11.4 kg) performed four modified scenarios of BZ during the competitive season. Modifications to BZ included reducing the field size, removal of a fielder, a combination of these modifications and tactical rule changes. The HR, [BLa], RPE and movement patterns of participants were measured during each scenario. The total distance covered per 8-over bout ranged from 626 ± 335 m for wicketkeepers to 1795 ± 457 m for medium-fast bowlers. Similar distances (p > 0.05) were covered within positions across the four different scenarios. Between scenarios, the greatest mean speed, HR and [BLa] resulted from the rule modifications, resulting in increased movement patterns (p < 0.05), most notably for batsmen and wicketkeepers. In contrast, altering the playing field size or player number did not significantly influence (p > 0.05) these demands. These results suggest that the physical demands of cricket-specific training can be manipulated via rule variations such as ‘hit-and-run’ activities, whereas changes to field size or player number appear to have a lesser influence.

Introduction

Originally used to develop the skills and tactical abilities of athletes in match-simulated environments, SSG are often also employed to improve physical capacities simultaneous to technical and tactical competencies (Hill-Haas et al., 2011). It has been reported that manipulations to the constraints of the SSG
playing environment significantly influences a player’s activity demands and the ensuing physiological responses (Foster et al., 2010; Hill-Haas et al., 2010; Owen et al., 2004). In order to correctly prescribe fluctuations in TL, coaches can manipulate the physical demands of a SSG training session through changing various constraints, although it is vital that the effect on the physiological, physical and technical responses is quantified. In regards to cricket, whilst the physical and physiological demands are considerable and prolonged, historically a greater training emphasis is placed on development of technical abilities rather than physical capacities (Bartlett, 2003; Bartlett et al., 1996; Burnett et al., 1995; Stretch et al., 2000). To accommodate both the physical and technical training demands within a cricket-specific context, BZ was developed, placing players in simulated, match-intensive environments (Renshaw et al., 2010). However, to date few studies have quantified the physical demands or physiological responses to BZ or how these responses are altered based on various types of BZ sessions.

Previous studies in FBTS such as soccer and rugby league training have shown that modifications to the number of players on the field can greatly influence the physiological responses to SSG training (Gabbett et al., 2009; Hill-Haas et al., 2010; Hill-Haas et al., 2009b; Impellizzeri et al., 2006). Specifically, increases in HR, [BLA] and RPE have been typically observed when the number of players is reduced (Foster et al., 2010; Hill-Haas et al., 2009b). However, somewhat counter-intuitively, decreasing player numbers during SSG has contrastingly been reported to have little effect on the physical demands, as evidenced by the similar distances travelled in total and within specific speed zones by youth
soccer players (Hill-Haas et al., 2009b; Jones & Drust, 2007). Conflicting data has also been reported for alterations to the size of the playing field. For example, Casamichana and Castellano (2010) reported increases in HR and RPE during soccer SSG played on a larger field; whereas Tessitore et al. (2006) reported that the greatest physiological responses were incurred on smaller sized fields.

Research in several FBTS has also indicated the physical and physiological demands can be manipulated via the use of altered playing rules, such as designating specific defensive and attacking zones or limiting the amount of possession by each player (Duarte et al., 2010; Gabbett et al., 2009; Hill-Haas et al., 2010; Hill-Haas et al., 2009c). Accordingly, it seems evident that the manipulation of the SSG constraints can affect the ensuing physical demands and physiological responses; which may result in changes in the imposed TL. However, research reporting on SSG has predominantly focused on FBTS such as soccer and rugby league (Foster et al., 2010; Jones & Drust, 2007; Kelly & Drust, 2009; Owen et al., 2004). Given the particular importance of match-specific, SSG training for cricket, further understanding of the effects of modifications to SSG constraints and resulting physical and physiological demands are required.

As demonstrated in Studies 3 and 4, a generic BZ training session provides cricket players with an adequate and consistent physical (mean speed: 25-66 m·min⁻¹; number of HI activities: 5-40) and physiological training stimulus (%HRmax: 79-91%; RPE: 4.2-6.0). Furthermore, the training stimulus of BZ
appears to be reliable and reproducible (mean speed: CV= 6.7-9.4, ICC= 0.56-1.00). However, these past studies have been limited to reporting on the physical and physiological demands and between-session reliability of a generic 6- or 8-over scenario of BZ. To date, no research reports the physiological and physical responses to various modifications of the original BZ format. Therefore, the objective of this study was to examine the effect of rule modifications, player numbers and playing field size on the physical demands and physiological responses during BZ.

Methods

Participants

During each of the different BZ scenarios, 11 amateur, cricket players (age 22.2 ± 3.6 yr; stature 1.80 ± 0.62 m; mass 81.7 ± 11.4 kg) were recruited. Participants were first and second grade players in a district standard cricket competition and performed two cricket-specific training sessions per week. Participants were classified as a batsman, medium-fast bowler, spin bowler, fielder or wicketkeeper according to their role during each bout. Participants gave verbal and written informed consent (see Appendix C) prior to any testing. The research was approved by the University of Newcastle Human Research Ethics Committee (H-2010-1288) (see Appendix D).
Procedures

Following familiarisation with all equipment and procedures, participants performed at least one BZ training session, for which the procedures and playing format have been described elsewhere (Studies 3-4). Briefly, each BZ session consisted of six repeat 8-over bouts on a cricket pitch surrounded by a 0.8 m high cricket net on the 30 yd (27.4 m) inner circle of a standard cricket field. One bout of BZ required two bowlers to complete four alternating overs to a batting pair, with the remaining participants fielding at specific positions on the BZ field. All participants performed as typical of a OD cricket match, with normal cricket rules and regulations (International Cricket Council, 2009) being applied to each session. For the present study, these procedures were then adapted based on the required modifications (field size, player number, field size-player number, and rule changes) for each of the four respective BZ scenarios. Each BZ session consisted of six bouts in total, of which each bout included 8 overs lasting 21 ± 2 min.

Battlezone Scenarios

Specific modifications were made to the generic BZ scenario based on common constraints used in other SSG studies, including player number, field size and rule alterations (Dellal et al., 2011a; Hill-Haas et al., 2010; Kelly & Drust, 2009). The specific variations to the generic BZ format in the current study included and can be seen on page 176:

1. Field size: the 0.8 m high cricket net was located in a circle 30 m in radius, measured from the centre of the pitch as opposed to the 30 yd (27.4 m) oval used during OD matches (International Cricket Council,
2009). This resulted in ~18% reduction in playing area from the generic version of BZ (Figure 7.1a) (over the page);

2. Player number: the number of fielders on the field during each bout was reduced to 3 (excluding the wicketkeeper) from the normal 4 players, with the “cover” position removed (Figure 7.1b);

3. Field size-player number: combination of both scenario 1 and 2 (Figure 7.1c), and;

4. Rule changes: The rules of the BZ session were modified as below:
   a. Batsmen must attempt a run after each ball that was hit;
   b. Instead of bowlers completing 6 consecutive deliveries for an over, bowlers rotated after each delivery until both had completed 4 overs each, and;
   c. Fielders were required to throw each ball back to the wicketkeeper’s end, as opposed to the bowler’s end following each play (Figure 7.1d).
Figure 7.1: Layout of BZ playing area for different scenarios for a right-handed batsmen.
Physiological Measures

The HR of each player was measured at 5 s intervals throughout each session (Polar Team\textsuperscript{2} System, Polar Electro Oy, Kempele, Finland). Prior to BZ data collection, participants completed the Yo-Yo Intermittent Recovery Test Level 1 whilst wearing a HR monitor. Each individual’s HR\textsubscript{max} was determined from the HR achieved prior to exhaustion during the Yo-Yo Intermittent Recovery Test Level 1. Measures of HR were expressed as a %HR\textsubscript{max} (Hill-Haas et al., 2009b) and classified into 5 intensity zones: Zone 1 (0-50\%HR\textsubscript{max}), Zone 2 (51-75\%HR\textsubscript{max}), Zone 3 (76-85\%HR\textsubscript{max}), Zone 4 (86-95\%HR\textsubscript{max}) and Zone 5 (>95\%HR\textsubscript{max}) (Study 2-4). The absolute and percentage of time spent within respective zones for each player during each training session were also calculated (Hill-Haas et al., 2009b).

Capillary blood samples (5 µl) were obtained from a hyperaemic earlobe of each batsmen and bowler within 3 min of leaving the playing area after an 8-over bout. Samples were immediately analysed for blood lactate (Lactate Scout, EKF Diagnostics, Magdeburg, Germany). Both batsmen and bowlers also provided a RPE CR-10 scale (Borg et al., 1987) after the 8-over bout. This protocol was completed throughout the entire training session for a total of six separate bouts of the same version of BZ.

Time-Motion Characteristics

MinimaxX GPS devices (v6.65, Catapult Innovations, Melbourne, Australia) sampling at 10 Hz measured the distance and speed of player’s movement patterns. Players wore a specially designed harness placing the GPS unit
between the shoulder blades. As instructed by the manufacturer, each GPS unit was turned on 15 min prior to players entering the playing area to ensure a satellite lock was established. Data was downloaded and analysed following each BZ session using customised software (Logan Plus 4.6 software, Catapult Innovations, Melbourne, Australia).

Speed zones used by previous research were selected for data analysis and consisted of: standing/walking (0-2.00 m·s⁻¹), jogging (2.01-3.50 m·s⁻¹), running (3.51-4.00 m·s⁻¹), striding (4.01-5.00 m·s⁻¹) and sprinting (>5.01 m·s⁻¹) (Petersen et al., 2010). Work-to-recovery ratio was defined as the ratio of time spent completing HI (running, striding, sprinting) to LI (standing/walking, jogging) activity (Petersen et al., 2010). The starting point of an 8-over bout within each SSG coincided with the initial increase in velocity using Logan Plus 4.6 software (Catapult Innovations, Melbourne, Australia).

**Statistical Analysis**

All data were reported as mean ± SD. Due to all players not being involved in each 8-over bout any data recorded whilst a player was not involved was disregarded. Data was assessed for normality using a Kolmogrov-Smirnov test. To determine the effect of playing environment, player number and rule modifications, the physiological and physical measures were compared with one-way repeated measures analysis of variance with Fisher’s Least Significant Difference post hoc (p < 0.05) test. Statistical analyses were performed using the software package IBM SPSS Statistics (version 19, IBM Corporation, Somers, New York, USA).
Results

The respective influence of reduced field size, reduced player number, reduced field size-player number and specific rule changes are described accordingly in the following sections specific to respective playing positions. The physiological responses of each playing position within each BZ scenario are presented in Table 7.1 (see page 181). Total distance within each movement category and mean speed within each scenario of each playing position are shown in Table 7.2 (see page 182). Finally, specific movement characteristics of each playing position during the respective BZ scenarios are presented in Table 7.3 (see page 184).

Batsmen

The highest peak %HR_{max} (p < 0.05) was observed in the rule changes session the HR_{mean} response between the different BZ scenarios (p > 0.05). Similarly, no significant difference (p > 0.05) in time spent within respective HR zones existed between the different scenarios. A main effect was present for RPE (F(3,30): 8.431; p ≤ 0.00; η^2 = 0.457) for batsmen across the different BZ formats. Post hoc analysis revealed that RPE was significantly higher (p < 0.05) during the rule changes format than all other variations, without differences between the other respective scenarios (p > 0.05). Lastly, [BLa'] did not differ (p > 0.05) between respective scenarios.

Total distance covered for batsmen did not differ (p > 0.05) between the various BZ scenarios (Table 7.2). However, a main effect was present between BZ formats for mean speed (F(3,30): 4.415; p < 0.02; η^2 = 0.306) and total sprinting
distance ($F(3,30): 4,737; p < 0.01; \eta^2 = 0.321$). Specifically, the rule changes scenario resulted in the highest ($p < 0.05$) mean speed and distance travelled whilst sprinting. A main effect was also present between BZ scenarios for work-to-recovery ratio ($F(3,30): 3.726; p < 0.05; \eta^2 = 0.293$), with a significantly shorter ($p < 0.05$) recovery time for batsmen evident during the rule changes scenario compared to the field size and player number scenarios. There were no other differences ($p > 0.05$) in the distance covered or speed zone movement characteristics for batsmen between other BZ scenarios.
Table 7.1: Physiological and perceptual responses by position during a bout of different BZ scenarios (mean ± SD).

<table>
<thead>
<tr>
<th>Scenario and Playing Position</th>
<th>HR$_{\text{mean}}$ (b/min$^{-1}$)</th>
<th>Peak %HR$_{\text{max}}$</th>
<th>HR Zones (% of time)</th>
<th>[BLa] (mmol.L$^{-1}$)</th>
<th>RPE (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone 1</td>
<td>Zone 2</td>
<td>Zone 3</td>
<td>Zone 4</td>
<td>Zone 5</td>
</tr>
<tr>
<td><strong>Field Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=11)</td>
<td>153 ± 12</td>
<td>89 ± 7</td>
<td>0</td>
<td>31 ± 28</td>
<td>47 ± 23</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=9)</td>
<td>145 ± 11</td>
<td>89 ± 6</td>
<td>0</td>
<td>39 ± 16</td>
<td>42 ± 13</td>
</tr>
<tr>
<td>Fielder (n=16)</td>
<td>133 ± 13</td>
<td>84 ± 7</td>
<td>1 ± 1</td>
<td>78 ± 24</td>
<td>17 ± 16</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>144 ± 3</td>
<td>83 ± 2</td>
<td>0</td>
<td>51 ± 17</td>
<td>49 ± 16</td>
</tr>
<tr>
<td><strong>Player Number</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=12)</td>
<td>156 ± 14</td>
<td>90 ± 7</td>
<td>0</td>
<td>27 ± 35</td>
<td>33 ± 21</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=8)</td>
<td>174 ± 13$^a$</td>
<td>89 ± 7</td>
<td>0</td>
<td>28 ± 29</td>
<td>34 ± 18</td>
</tr>
<tr>
<td>Spin Bowler (n=4)</td>
<td>132 ± 6</td>
<td>77 ± 6</td>
<td>0</td>
<td>91 ± 13</td>
<td>6 ± 8</td>
</tr>
<tr>
<td>Fielder (n=12)</td>
<td>134 ± 19</td>
<td>84 ± 9</td>
<td>1 ± 3</td>
<td>71 ± 34</td>
<td>16 ± 19</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>151 ± 11</td>
<td>87 ± 4</td>
<td>18 ± 40</td>
<td>27 ± 32</td>
<td>31 ± 33</td>
</tr>
<tr>
<td><strong>Player Number and Field Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=12)</td>
<td>147 ± 13</td>
<td>86 ± 7</td>
<td>2 ± 5</td>
<td>47 ± 37</td>
<td>36 ± 23</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=10)</td>
<td>148 ± 9</td>
<td>87 ± 5</td>
<td>0</td>
<td>49 ± 27</td>
<td>35 ± 10</td>
</tr>
<tr>
<td>Spin Bowler (n=2)</td>
<td>162 ± 5$^b$</td>
<td>92 ± 5$^b$</td>
<td>0</td>
<td>9 ± 1$^b$</td>
<td>61 ± 20</td>
</tr>
<tr>
<td>Fielder (n=11)</td>
<td>129 ± 20</td>
<td>79 ± 9</td>
<td>7 ± 15</td>
<td>72 ± 34</td>
<td>12 ± 17</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>129 ± 4$^{a,b}$</td>
<td>81 ± 4$^{a,b}$</td>
<td>1 ± 3</td>
<td>92 ± 3$^{a,b}$</td>
<td>5 ± 3$^a$</td>
</tr>
</tbody>
</table>

*Significantly (p < 0.05) different to field size scenario; $^a$Significantly (p < 0.05) different to player number scenario; $^c$Significantly (p < 0.05) different to field size and player number scenario.
Table 7.2: Movement category distances by position during a bout of different BZ training scenarios (mean ± SD).

<table>
<thead>
<tr>
<th>Scenario and Playing Position</th>
<th>Distance Covered (m)</th>
<th>Mean Speed (m min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walking</td>
<td>Jogging</td>
</tr>
<tr>
<td>Field Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=11)</td>
<td>548 ± 75</td>
<td>306 ± 75</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=9)</td>
<td>981 ± 356</td>
<td>220 ± 67</td>
</tr>
<tr>
<td>Fielder (n=16)</td>
<td>806 ± 201</td>
<td>359 ± 304</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>468 ± 172</td>
<td>113 ± 115</td>
</tr>
<tr>
<td>Player Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=12)</td>
<td>532 ± 63</td>
<td>339 ± 93</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=8)</td>
<td>1085 ± 316</td>
<td>251 ± 83</td>
</tr>
<tr>
<td>Spin Bowler (n=4)</td>
<td>801 ± 91</td>
<td>350 ± 168</td>
</tr>
<tr>
<td>Fielder (n=12)</td>
<td>793 ± 175</td>
<td>375 ± 357</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>447 ± 131</td>
<td>86 ± 50</td>
</tr>
<tr>
<td>Player Number and Field Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=12)</td>
<td>548 ± 73</td>
<td>320 ± 57</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=10)</td>
<td>1184 ± 238</td>
<td>305 ± 121</td>
</tr>
<tr>
<td>Spin Bowler (n=2)</td>
<td>690 ± 243</td>
<td>198 ± 160b</td>
</tr>
<tr>
<td>Fielder (n=11)</td>
<td>809 ± 283</td>
<td>278 ± 205</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>570 ± 228</td>
<td>139 ± 104</td>
</tr>
<tr>
<td>Rule changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=12)</td>
<td>506 ± 48</td>
<td>326 ± 57</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=8)</td>
<td>779 ± 149b,c</td>
<td>221 ± 48</td>
</tr>
<tr>
<td>Spin Bowler (n=4)</td>
<td>719 ± 88b</td>
<td>255 ± 58</td>
</tr>
<tr>
<td>Fielder (n=17)</td>
<td>681 ± 137</td>
<td>480 ± 306</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>481 ± 114</td>
<td>103 ± 52</td>
</tr>
</tbody>
</table>

*a* Significantly (*p* < 0.05) different to field size scenario; *b* Significantly (*p* < 0.05) different to player number scenario; *c* Significantly (*p* < 0.05) different to field size and player number scenario.
Medium-Fast Bowlers

For the medium-fast bowlers, a main effect was observed for HR\textsubscript{mean} (F(3,21): 13.778; \( p \leq 0.00; \eta^2 = 0.663 \)) between BZ scenarios. Specifically, a significantly \((p < 0.05)\) higher HR\textsubscript{mean} was observed during the decreased player number format compared to all other scenarios. Further to this, the percentage of time spent within each HR zone did not differ \((p > 0.05)\) between the BZ scenarios. Alternatively, a main effect \((F(3,21): 3.659; p < 0.030; \eta^2 = 0.343)\) was evident for [BLa\textsuperscript{-}] between the different BZ scenarios; with the field size-player number scenario resulting in a significantly \((p < 0.05)\) lower [BLa\textsuperscript{-}] compared to the respective field size and player number scenarios. The RPE of medium-fast bowlers following each bout was not different \((p > 0.05)\) between the respective scenarios.

Measures of total distance and HI movement characteristics were not different \((p > 0.05)\) between scenarios for medium-fast bowlers. A main effect \((F(3,21): 3.988; p < 0.03; \eta^2 = 0.363)\) was evident for total walking distance covered between BZ scenarios, with a significantly lower distance \((p < 0.05)\) covered during the rule changes scenario compared to the player number or field size-player number.
Table 7.3: Movement characteristics by position during a bout of different BZ training scenarios (mean ± SD).

<table>
<thead>
<tr>
<th>Scenario and Playing Position</th>
<th>HI Efforts (#)</th>
<th>Sprints (#)</th>
<th>Mean Sprint Distance (m)</th>
<th>Work-to-Recovery Ratio (1:x)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=11)</td>
<td>57 ± 23</td>
<td>7 ± 5</td>
<td>9 ± 2</td>
<td>19 ± 8</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=9)</td>
<td>49 ± 18</td>
<td>1 ± 2</td>
<td>3 ± 5</td>
<td>22 ± 12</td>
</tr>
<tr>
<td>Fielder (n=16)</td>
<td>32 ± 15</td>
<td>3 ± 2</td>
<td>6 ± 3</td>
<td>41 ± 32</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>10 ± 11</td>
<td>1 ± 1</td>
<td>8 ± 5</td>
<td>238 ± 143</td>
</tr>
<tr>
<td><strong>Player Number</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Batsman (n=12)</td>
<td>46 ± 11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4 ± 2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9 ± 2</td>
<td>21 ± 8</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=8)</td>
<td>64 ± 16</td>
<td>4 ± 6</td>
<td>8 ± 6</td>
<td>16 ± 8</td>
</tr>
<tr>
<td>Spin Bowler (n=4)</td>
<td>22 ± 11</td>
<td>5 ± 3</td>
<td>10 ± 5</td>
<td>46 ± 35</td>
</tr>
<tr>
<td>Fielder (n=12)</td>
<td>30 ± 17</td>
<td>3 ± 3</td>
<td>8 ± 4</td>
<td>35 ± 16</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>7 ± 8</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>188 ± 97</td>
</tr>
<tr>
<td><strong>Player Number and Field Size</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batsman (n=12)</td>
<td>60 ± 17</td>
<td>6 ± 4</td>
<td>6 ± 3</td>
<td>17 ± 6</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=10)</td>
<td>52 ± 19</td>
<td>3 ± 4</td>
<td>5 ± 4</td>
<td>20 ± 8</td>
</tr>
<tr>
<td>Spin Bowler (n=2)</td>
<td>19 ± 18</td>
<td>2 ± 2</td>
<td>2 ± 1</td>
<td>111 ± 114</td>
</tr>
<tr>
<td>Fielder (n=11)</td>
<td>34 ± 17</td>
<td>4 ± 4</td>
<td>9 ± 3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>39 ± 22</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>8 ± 2</td>
<td>1 ± 1</td>
<td>5 ± 2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>189 ± 80</td>
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<tr>
<td><strong>Rule changes</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Batsman (n=12)</td>
<td>61 ± 15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8 ± 4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9 ± 2</td>
<td>12 ± 3&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Medium-Fast Bowler (n=8)</td>
<td>50 ± 26</td>
<td>6 ± 9</td>
<td>6 ± 5</td>
<td>23 ± 20</td>
</tr>
<tr>
<td>Spin Bowler (n=4)</td>
<td>7 ± 2</td>
<td>1 ± 1</td>
<td>10 ± 7</td>
<td>58 ± 30</td>
</tr>
<tr>
<td>Fielder (n=17)</td>
<td>31 ± 14</td>
<td>3 ± 2</td>
<td>9 ± 5</td>
<td>23 ± 17</td>
</tr>
<tr>
<td>Wicketkeeper (n=6)</td>
<td>12 ± 6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2 ± 1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9 ± 2&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>55 ± 12&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Significantly (p < 0.05) different to field size scenario; <sup>b</sup> Significantly (p < 0.05) different to player number scenario; <sup>c</sup> Significantly (p < 0.05) different to field size and player number scenario.
Spin Bowlers

There was a significant main effect was evident for HR\textsubscript{mean} ($F(2,2)$: 1112.333; $p \leq 0.01; \eta^2 = 1.000$), peak %HR\textsubscript{max} ($F(2,2)$: 111.422; $p \leq 0.01; \eta^2 = 0.991$) and the percentage of time spent within HR Zone 2 ($F(2,2)$: 20.355; $p \leq 0.05; \eta^2 = 0.953$) between the different BZ scenarios for spin bowlers. Subsequent post hoc analyses revealed the HR response of spin bowlers was highest during the field size-player number scenario ($p < 0.05$) (Table 7.1). Furthermore, significantly less time ($p < 0.05$) was spent within HR Zone 2 during the field size-player number scenario than during the other scenarios. Both the [BLa] and RPE of spin bowlers did not differ ($p > 0.05$) between the respective scenarios. Furthermore, no main effects ($p > 0.05$) for measures of total distance or any movement characteristics were observed between BZ scenarios.

Fielders

No significant differences ($p > 0.05$) were observed for HR, [BLa] or RPE responses between any of the respective BZ scenarios during fielding activities. Furthermore, there were no main effects ($p > 0.05$) for measures of total distance or any movement characteristics observed between different scenarios.

Wicketkeepers

A main effect was reported for HR\textsubscript{mean} ($F(3,12)$: 8.200; $p \leq 0.01; \eta^2 = 0.653$), %HR\textsubscript{max} ($F(3,12)$: 4.016; $p \leq 0.05; \eta^2 = 0.501$) and the percentage of time within HR Zone 2 ($F(3,12)$: 7.518; $p \leq 0.01; \eta^2 = 0.653$) and Zone 3 ($F(3,12)$: 3.656; $p \leq 0.05$; $\eta^2 = 0.500$) between the different BZ scenarios for wicketkeepers. Subsequent post hoc analyses revealed the HR response of wicketkeepers was highest during the field size-player number scenario ($p < 0.05$) (Table 7.1). Furthermore, significantly less time ($p < 0.05$) was spent within HR Zone 2 during the field size-player number scenario than during the other scenarios. Both the [BLa] and RPE of wicketkeepers did not differ ($p > 0.05$) between the respective scenarios. Furthermore, no main effects ($p > 0.05$) for measures of total distance or any movement characteristics were observed between BZ scenarios.
Post hoc analyses revealed a significantly lower HR\textsubscript{mean} ($p < 0.05$) in the field size-player number scenario compared to all others (Table 7.1). Further, a significantly greater time ($p < 0.05$) was spent in HR Zone 3 during the rule changes scenario in comparison to the field size-player number scenario.

Separately, the distance travelled at a striding pace showed a main effect ($F(3,12): 4.231; p \leq 0.05; \eta^2 = 0.514$) across the BZ scenarios for wicketkeepers. Post hoc analysis revealed that wicketkeepers travelled the greatest distance at striding speeds in the rule changes scenario compared to the player number and field size-player number scenarios (Table 7.2). A main effect was also evident for the number of sprints performed per bout ($F(3,13):3.500; p \leq 0.05; \eta^2 = 0.467$) and for mean sprint distance ($F(3,12): 8.649; p \leq 0.01; \eta^2 = 0.684$) across scenarios. Post hoc analysis revealed that a greater number of HI efforts and sprints, mean sprint distance and a shorter work-to-recovery ratio resulted from the rule changes scenario ($p < 0.05$) when compared to the other scenarios (Table 7.3).

**Discussion**

The aim of this study was to examine the movement demands and physiological responses of cricket players during various formats of BZ training. The results demonstrated that the physiological and physical responses to different BZ match scenarios were affected to varying degrees when specific rule modifications were introduced, and changes to player numbers and the playing field size were made. Specifically, variations to the BZ playing rules (i.e. ‘hit-
and-run’ or alternating ball delivery), appeared to have the greatest increase on
the physiological and physical demands, particularly with respect to the
demands of batsmen and wicketkeepers. These findings provide evidence that
coaches can use BZ variations to manipulate TL’s to implement match-specific
training stimuli for cricket players, and as such, contribute to a periodised
training plan.

**Batsmen**

The current data demonstrated that changing the playing rules of BZ caused
larger fluctuations in the physiological and physical demands of batsmen than
the other BZ format changes. Despite similar total distances being covered by
batsmen in each scenario per 8-over bout, the rule changes scenario resulted in
a faster mean running speed, which was reflected with an increased number of
HI efforts and a reduced work-to-recovery ratio. The increased movement
demands of this scenario is logically explained by the requirements of the ‘hit-
and-run’ rule change resulting in batsmen engaging in an increased volume of
higher-velocity efforts coupled with less recovery. Consequently, these
movement demands may explain the higher HR responses and RPE values
also observed throughout the rule change scenario. In comparison, the other BZ
scenarios, including reduced player number or field size did not alter any
measures of physiological or perceptual load (i.e. HR, [BLa'] and RPE).

The results of the current study are similar to findings that have described
variations to SSG in other sports, whereby specific rule changes were also
shown to significantly influence physiological and physical demands (increased
%HR_{\text{max}} and RPE, higher running intensity demands) (Hill-Haas et al., 2010; Hill-Haas et al., 2009c). Unlike previous SSG research (Hill-Haas et al., 2010; Owen et al., 2004; Rampinini et al., 2007), alterations to the field size or the number of players on the field were shown to have no significant effect on the demands of BZ training. One possible explanation for the lack of aforementioned differences between BZ scenarios may relate to the technical nature of cricket, rather than a heavy reliance on a player’s aerobic fitness and voluntary running. In the majority of BZ formats, batsmen were instructed to bat as they typically would during an OD cricket match. However, during the rule changes scenario batsmen were placed into non-typical batting situations, such as running after hitting the ball when a run would not normally be taken or sprinting to one particular end of the pitch to ensure they were not out. Accordingly, the rule changes scenario significantly increased the running demands of batsmen, which thereby increased physiological and perceptual responses. Furthermore, in comparison to that previously reported for generic BZ training (Studies 3 and 4), the rule changes scenario provided a more physical and physiologically intensive training environment. In particular, a greater amount of time was spent performing above 75\%HR_{\text{max}} during the rule changes scenario when compared to the generic setting (Rule change: 71 ± 59%; Generic: 65 ± 42%), which was a contributing factor in a higher RPE being reported (Rule change: 7.4 ± 1.6; 4.9 ± 1.4). Based on such findings, to increase the physical conditioning load of batsmen, the rule changes scenario may be used to increase the running demands, although an important consideration is the ensuing effect on technical performance.
Medium-Fast Bowlers

The \( \text{HR}_{\text{mean}, \ [\text{BLa}]} \) and the distance travelled at walking speed significantly differed between the various BZ scenarios, with no single BZ scenario providing medium-fast bowlers with a significantly greater physical training demand. The similarity in the required total of ball deliveries performed by medium-fast bowlers during BZ (e.g. similar number of bowling deliveries per bout over a similar distance) may have contributed to the lack of difference in movement demands between the scenarios. Unlike the batsmen who were forced to alter movement patterns during rule changes, the bowlers retained similar movement demands and physiological responses across all variations of BZ used. Furthermore, while an increased movement demand (mean speed, number of HI efforts) was noted in batsmen for the rule change scenario, the design of the rule changes scenario may have contributed to shorter distances covered for bowlers by combining the 2 x 4 over bowling spells into a singular bout of 8 overs.

In comparison to a generic BZ setting, the physical demands of medium-fast bowlers were increased when variations were made to the playing rules or environment (compared to Studies 2-3). A considerably greater distance was covered at a higher speed, combined with a greater number of HI efforts and a reduced work-to-recovery ratio when changes were made to the constraints of a generic BZ scenario. However, changes made to the generic BZ sessions did not influence the physiological responses of medium-fast bowlers, despite changes in their movement characteristics (Studies 3 and 4). As reported in these previous studies, a generic BZ scenario provided medium-fast bowlers
with a similar physiological load as match-intensive environments. Therefore, the results of the current study suggest that the physiological stimulus of medium-fast bowlers were maintained across all BZ formats and as such any of the BZ scenarios used were suitable in providing an appropriate match-simulated load when compared to a relative time-matched duration of a match (Petersen et al., 2010).

**Spin Bowlers**

Changes within the BZ scenarios resulted in varied physiological responses and physical demands of spin bowlers. Despite the field size-player number scenario appearing to increase the \( \text{HR}_{\text{mean}} \) and peak \( \% \text{HR}_{\text{max}} \), this increase in was not reflected in \([\text{BLa}]\) or RPE. The physical demands of spin bowlers varied between scenarios, with the slowest mean speed and longest work-to-recovery ratio being present in the reduced field size-player number. The low number of spin bowlers used in the current study presents a limitation in interpreting these physiological responses and movement characteristics, and hence future research should increase the number of spin bowlers used in BZ studies. Similar to medium-fast bowlers, regardless of the BZ format, the intensity and physical demands resulting from BZ may be adequate to provide spin bowlers with a simulated match-intensive stimulus.

**Fielders**

The respective changes to the BZ scenarios did not significantly change the physiological responses and physical demands of fielders in the current study. These results were surprising as the modifications to the SSG environment
altered both the physical demands of batsmen and bowler, which in turn, may be suggestive of global changes in SSG intensity. It is possible that the different skill levels of the batsmen and bowlers (e.g. batsmen favouring leg-side or off-side shots, bowlers favouring a shorter or fuller length delivery), or the changes to the BZ rules perhaps being biased more towards changes in demands of batsmen and bowlers, resulted in similarity between scenarios for physiological response and movement characteristics of fielder

Despite no differences in the HR, [BLa'] and RPE measures for fielders, the results of the present study differ to that previously reported in Study 3 and 4 for the demands of fielding during a generic BZ format. Modifications to the field size, player number and playing rules appeared to increase the physical demand of fielders, potentially providing a greater internal TL (HR and RPE), despite similar external loads (distance covered). In particular, fielders within the rule changes scenario demonstrated a considerably higher %HR\textsubscript{max} combined with a greater total distance covered and a higher mean speed per bout (Study 3). Additionally, a greater number of HI efforts and a shorter recovery time were reported during the rule changes scenario as opposed to a generic BZ scenario. Therefore, although the intensity and physical demands of fielders did not differ between BZ variations, changes to the playing environment or rules provide players within an increased intensity and physical demand compared to previous research on a generic BZ design (Study 3).
Wicketkeepers

The modification of BZ scenarios resulted in increased physiological and physical demands of wicketkeepers, when compared to a generic BZ session (Study 3). Similar to batsmen, the rule changes scenario had the greatest effect on the physiological responses and movement characteristics of wicketkeepers. Although similar HR responses were reported between the various scenarios that manipulated field size, player number and rule changes formats, the latter composition evoked the greatest time spent above 75%HR_{max}. The considerably shorter recovery time between HI efforts in comparison to the other scenarios may also have contributed to the increased physiological responses of the rule changes scenario. Unfortunately, as the RPE of wicketkeepers was not recorded, it remains unknown if the perceived intensity of wicketkeepers changed with modifications to BZ. Regardless, the increased distance covered at striding pace by wicketkeepers can also be attributed to the rule changes made to the BZ session, likely requiring faster movement to the stumps due to the more regular running of the batsmen. Based on these findings, the physiological responses of wicketkeepers can be influenced by having the fielders only return the ball back to the wicketkeeper’s end of the pitch during a BZ training session.

Conclusion

In order to manipulate the TL’s achieved through the use of BZ training, this study aimed to compare the physiological and physical demands of various forms of BZ. The major finding suggests that the introduction of different playing rules (i.e. ‘hit-and-run’) posed the greatest influence on training intensity
compared to other BZ scenarios such as changes in field size or player number, specifically for batsmen and wicketkeepers. In contrast to previous research with other team sports (Hill-Haas et al., 2010; Hill-Haas et al., 2009b; Owen et al., 2004), changes to the playing field size had minimal effect on training intensity, particularly for medium-fast bowlers, spin bowlers and fielders. Regardless, the information from this study may be useful for coaches requiring manipulation of TL’s through the use of SSG to implement match-specific training stimuli for cricket players. Given the intensity sustained during the various BZ scenarios, combined with the ease at which different cricket match situations can be created within the playing area, BZ may be more suitable as a training practice for the shorter cricket formats (OD and T20 matches). Future research should further aim to determine if the technical skills of players such as the accuracy of the bowlers or the quality of the shots played by batsmen are able to be influenced by changes to the playing environment and rules.

**Practical Applications**

- The use of different BZ scenarios appears to provide range of match-specific training environments suitable for developing the physical conditioning status of cricket players.
- Due to the increased movement demands of the ‘rule changes’ scenario, coaches may choose this scenario when looking to develop the conditioning status of their players. Coaches may choose to include new rule changes when developing training programs to better suit their own training objectives.
• Decreasing the size of the BZ playing field and/or decreasing the number of fielders on the BZ playing area may be more suitable at developing the technical skills and ‘game sense’ abilities of players as these scenarios appear more replicable to a typical OD match.
Chapter 8

Discussion
Overview of Thesis

This thesis examined the use of game-based training, specifically designed for cricket as an effective training method to provide a match-specific TL. Primarily the research investigated the associated physiological responses and physical demands placed upon players during various traditional and game-based training methods, as well as match-play. More specifically, this thesis contains several studies that aimed to investigate training and monitoring of applied cricket training, including:

1. The accuracy and reliability of 5, 10 and 15 Hz GPS devices for quantifying sport-specific movements (Study 1);
2. Differences in the physiological, physical and technical loads of elite and amateur cricket players during game-based, TCT methods and competitive matches (Study 2 and 4);
3. The physiological and physical loads imposed on amateur cricket players during generic BZ training and the between-session reproducibility (Study 3), and;
4. The effect of modifications to the BZ playing environment and rules on the physiological and physical loads of amateur cricket players (Study 5).

In turn, the outcomes of each study will be collectively discussed below to demonstrate findings from the series of research studies.
Accuracy and Reliability of GPS during Cricket-Specific Activities

To ensure that measures of external load were of high-quality throughout the course of this research, the accuracy and reliability of the GPS devices used to determine physical demands in Studies 2-5 was examined. While the accuracy and reliability of GPS devices for cricket-specific activities has been previously documented (Petersen et al., 2009a), advancements in GPS technology has required further research. The results of Study 1 suggested that when performing short, high-speed and multi-directional efforts typical of cricket and other FBTS, the 10 Hz GPS devices underreported distances covered and speeds reached (Duffield et al., 2010; Jennings et al., 2010a). Previously, it has been suggested that improvements in the sampling frequency of GPS devices would increase the accuracy and reliability of distance and speed measurements (Jennings et al., 2010a; Portas et al., 2010). However, the current data demonstrated that an increase in sampling frequency failed to improve the accuracy of the GPS devices for FBTS activities. These findings continue to support that GPS devices underreport measures of distance and speed when compared to criterion measures from VICON (Duffield et al., 2010).

Furthermore, the findings presented in Study 1 demonstrated that the GPS devices possessed moderate reliability (cricket movements CV: 5.5-27.1%) during high-speed, short and multi-directional movements. This is similar to previous data that has reported on GPS devices that sample at a lower frequency (Coutts & Duffield, 2010; Duffield et al., 2010). Therefore, this current evidence presented data that should be acknowledged as a limitation to the
external loads reported in the remaining studies on the use of various training formats and match-play in cricket. Despite these limitations, the use of GPS technology remains a viable and practical means of quantifying such external TL’s in cricket, compared to alternative means (i.e. time-motion video analysis) that are also influenced by a degree of variability. From this study, protocols were implemented to minimise the variance of external load data across players when it came to distributing GPS units across players in order to improve data quality and interpretation of the outcomes.

**Differences between Centre-Wicket Practice, Traditional Cricket Training and Match-Play**

Typical cricket training practices are based on traditional methods that usually involve isolated skill training in nets or game-based training on a cricket field, appear not to provide players with match-specific situations. As such, Study 2 compared the intensity and demands of current training methods (TCT and CW) to a typical OD cricket match. Study 2 demonstrated that neither CW simulation nor TCT provided a more physically and physiologically demanding environment than match-play for the physical conditioning of cricket players. Similar to Farrow et al. (2008), CW simulations appeared to place batsmen in a more physically intense training environment as opposed to the net-based training sessions, due to the need to run between wickets. In contrast, medium-fast bowlers demonstrated the highest intensities during TCT rather than CW simulations, and importantly, selected measures were also greater than observed during a typical OD cricket match. Equivocal responses were reported
in spin bowlers, fielders and wicketkeepers, with no clear evidence suggesting one specific training format was more advantageous. Collectively, the physical and physiological demands of playing a OD match was observed to exceed that of either TCT or CW practice. Therefore, it might be suggested that neither training format provided cricket players with a match-specific conditioning response, which may limit physiological adaptation and skill transference.

Alternatively, Study 2 demonstrated that regardless of playing position, there was a greater technical demand during TCT when compared to CW simulation. When reported relative to duration, the data demonstrated that batsmen, bowlers and fielders completed a higher volume of balls faced, balls bowled and balls thrown, during TCT than CW simulations. Similar findings were made by Farrow et al. (2008) in Australian football players who were observed to execute a significantly greater number of skills such as handballs and disposals during ‘closed’ or typical skills sessions compared to game-based training.

As such, for the purposes of improving the technical abilities of a cricket player, TCT appears to be an advantageous training format as opposed to the game-based CW simulations. However, the disadvantage of ‘closed’ skill training methods such as TCT is the lack of match-specific practice which incorporates elements of decision-making and match awareness, in addition to the LI physical demands. Therefore, it was suggested that the development of more effective game-based training method which placed greater emphasis on physical and technical demands would allow the concurrent development of the physical conditioning and technical ability of cricket players.
Development of a Small-Sided Game for Cricket: The Introduction of Battlezone

Initially, Renshaw and colleagues (2010) developed BZ to provide cricket players with a match-intensive training environment that may improve transference of cricket-specific skills into match play. Since then, no research has examined the match-intensive qualities associated with the BZ training. Historically, cricket training has comprised of isolated net-based training and CW sessions for skill development and conditioning sessions for physiological conditioning (Pyke & Davis, 2010). The collective results from Studies 3-5 suggested that BZ was effective at providing match-appropriate TL. Further to this, within specific playing positions, the training demands observed during BZ exceeded that of a typical OD match. Taken together, these results supported the initial assumptions of Renshaw et al. (2010), that BZ provides a match-specific intensity whereby cricket players are required to execute technical skills. A brief summary of the outcomes for BZ across each playing position is presented below.

Batsmen

The collective data from Studies 3-5 demonstrated that batsmen performed at greater physical intensities during BZ or CW simulations than that during OD match-play at either an amateur (Study 4) or elite level of competition (Study 2; Petersen et al., 2010). This is strongly supported by the greater relative distance covered during the generic BZ session (3857 ± 910 m h⁻¹), of which between 20-32% was completed at a HI (OD match [Study 3 and Petersen et al. (2010)]: total distance: 2198 ± 757 m h⁻¹; HI distance: 14-16%). Further to this,
manipulating BZ constraints resulted further increases intensity for batsmen performing at higher intensities, with a considerably faster mean speed (BZ [Study 5]: 39 ± 9 m·min⁻¹; OD [Study 4 and Petersen et al. (2010)]: 34 ± 17 m·min⁻¹ and 41 ± 12 m·min⁻¹, respectively). The current data demonstrated that BZ is an effective conditioning training format for batsmen, as it required them to work at a relatively greater intensity.

Regardless of the BZ scenario used there was a greater physical demand placed on batsmen opposed to a cricket match, resulting in a higher physiological strain (BZ: time >75%HRmax: 66± 52%; OD: 58 ± 35%). Further, the RPE of the batsmen during a generic BZ training session was of a greater intensity then during competitive match-play (BZ: 4.9 ± 0.7; OD: 4.2 ± 1.5). The manipulation of the BZ environment, in particular changing the playing rules resulted in a further increase in RPE (7.4 ± 1.6). Whilst in the studies of Houghton et al. (2011a, 2011b), reported a similar RPE during a simulated batting innings to that of a match, during which batsmen were required to perform for a considerably greater duration. This led to a greater percentage of the overall TL being completed at a LI. This perceived intensity of BZ supports the greater relative intensity of the training format. The increased physiological and perceptual responses of batsmen during BZ suggested that it is useful for improving the conditioning status of cricket players (Foster et al., 2010; Hill-Haas et al., 2009b).

Separately, data from Study 4 suggested that BZ provides sufficient opportunity for the development of a batsman’s technical skill. In particular, batsmen faced
a greater relative number of balls and had a greater percentage of good contacts when compared to OD match-play. From a cricket-specific perspective, the increased technical element of BZ training is directly influenced by the match-specific environment (i.e. the volume of technical skill completed by batsmen is dependent on factors such as the placement of the ball by bowlers, position of the fielders or environmental factors). Most notably, a major influence was that batsmen were required to ‘score runs’ or run between the wickets as typical of a OD or T20 match, with the additional pressure from fielders and an enclosed environment. When the increased running demands were combined with the match-specific environment of BZ, these factors appeared to limit the recovery time between facing deliveries as well as the recovery between HI activities such as running between the wickets. As such, BZ provided batsmen with a demanding physical conditioning stimulus that may have also been a suitable environment for the rehearsal of technical skills and match awareness.

**Medium-Fast Bowlers**

Studies 3 and 4 demonstrated that medium-fast bowlers were also provided with a significant physical stimulus during BZ training. The average relative distance covered during a generic BZ session was $4320 ± 1284 \text{ m h}^{-1}$ with 13-21% of this completed through HI activities, which translated to a mean speed of $77 ± 20 \text{ m min}^{-1}$. During TCT, medium-fast bowlers performed at a similar physical demand (relative total distance: $4249 ± 1125 \text{ m h}^{-1}$; mean speed: $71 ± 19 \text{ m min}^{-1}$) (Study 4). By comparison, the physical demands of medium-fast bowlers exceeded that of a OD match (relative total distance: $3389 ± 1038 \text{ m h}^{-1}$)
mean speed: 54 ± 15 m·min⁻¹) (Study 4). In addition, the physical demands of medium-fast bowlers were increased by manipulating BZ constraints, with Study 5 reporting that measures of total distance covered (4415 ± 1391 m·h⁻¹), work-to-recovery ratio (20 ± 12 s) and the number of HI efforts completed (156 ± 57 #·h⁻¹) could be significantly increased when compared to the generic BZ session within Study 3 (3400 ± 833 m·h⁻¹, 46 ± 29 s, 83 ± 37 #·h⁻¹, respectively). Despite the disparity in duration between a typical OD match and BZ training session, Studies 3, 4 and 5 collectively demonstrated that greater relative physical demands (as expressed by distances covered and movement characteristics per unit of time) were required by amateur medium-fast bowlers during a BZ setting, than that of either amateur (Study 4) or elite medium-fast bowlers (Petersen et al., 2010; Petersen et al., 2009c) across a OD match.

This observed increase in the physical demands of medium-fast bowlers facilitated an increase in measures of physiological intensity (as expressed by measures of HR, [BLa'] and RPE) of medium-fast bowlers. Regardless of the BZ scenario, medium-fast bowlers demonstrated a greater HR_mean response during BZ (153 ± 16 b·min⁻¹), with a greater amount of time at higher HR intensities (>75%HR_max) than a typical OD cricket match (BZ [Studies 2-5]: 57 ± 39%; OD [Studies 2 and 4]: 37 ± 20%). In contrast to batsmen, the increase in physiological intensity was not supported by a higher perception of intensity by medium-fast bowlers during BZ. Medium-fast bowlers tended to report a greater RPE during a OD match (Study 4) (BZ: 5.2 ± 1.4; OD: 7.4 ± 0.9). However, manipulating BZ constraints, particularly the implementation of new playing rules; resulted in medium-fast bowlers reporting a higher RPE (5.7 ± 1.1).
Previous research using match simulations have reported a greater perceptual response amongst medium-fast bowlers however, this increase in RPE could possibly be attributed to the number of deliveries completed combined with scheduled LI activity (Duffield et al., 2009).

Study 4 demonstrated an increase in the relative volume of technical skills executed by medium-fast bowlers (# balls bowled) during the BZ scenarios compared to a OD match (BZ: 78 ± 14 # balls·h⁻¹; OD: 17 ± 5 # balls·h⁻¹). However, it is acknowledged that a maximum of 60 legal deliveries can be performed by an individual medium-fast bowler during a OD match, whereas during any training format, the number of deliveries is only limited by the recommendations of the coaching staff. Previously, the use of SSG within other sports has been criticised for the sole purpose of skills training (Gabbett et al., 2009). However, this current evidence suggested that BZ provides a training environment that provides an adequate physical conditioning stimulus and environment to enhance technical skill development for medium-fast bowlers.

Collectively, data taken from Studies 2 and 4 and in addition to previous simulated and match-play data (Duffield et al., 2009; Petersen et al., 2010) demonstrated that cricket match-play is likely to place a greater absolute load on medium-fast bowlers when compared to a BZ training session. In particular, a considerably greater overall distance was completed during a OD match (OD: 9530 ± 2654 m; BZ: 1196 ± 477 m [Study 4]). This is unsurprising given the longer duration of a typical OD match compared to BZ, combined with increased size of the playing area. However, as in the study of Casamichana et
al. (2012) in which soccer SGG resulted in a greater mean speed per session than a match, the relative demands of BZ exceeded that of a OD match within medium-fast bowlers (relative distance covered: BZ: $4970 \pm 1735$ m min$^{-1}$; OD: $3389 \pm 1038$ m min$^{-1}$). Based on this information, the greater relative demands of BZ are likely to provide medium-fast bowlers with a match-appropriate TL within a shorter period of time, limiting the absolute TL they are exposed to.

**Spin Bowlers**

The data reporting on spin bowlers demonstrated that BZ provided training intensities similar to that of match-play, as observed in Studies 2, 3 and 4. In comparison to a BZ session ($1013 \pm 175$ m) spin bowlers covered a considerably greater distance over the course of an entire OD match ($7555 \pm 2612$ m). However, spin bowlers covered a slightly greater relative distance during a generic BZ session ($2923 \pm 630$ m h$^{-1}$) than a OD match ($2618 \pm 793$ m h$^{-1}$). Further still, an even greater relative distance was covered when the playing environment and playing rules of the BZ scenarios was manipulated ($3235 \pm 227$ m h$^{-1}$). Similar relative distances were covered by elite spin bowlers during a OD match in the study of Petersen et al. (2010) ($3166 \pm 687$ m h$^{-1}$), with a similar relative HI activity completed to BZ (BZ: 9 ± 23%; Petersen et al. (2010): 9 ± 21%). The current data demonstrated that the use of different BZ scenarios (Study 5) may provide an even greater physical demand in comparison to that of a OD match. Despite this similar physical demand, a greater number of HI efforts were performed by spin bowlers in BZ, regardless of the scenario (Studies 2-5: $43 \pm 29$ # h$^{-1}$) as opposed to a typical OD match (Study 2 and 4: $33 \pm 26$ # h$^{-1}$; Petersen et al. (2010): $39 \pm 16$ # h$^{-1}$). This
information suggested that the relative physical demand created during BZ is representative of the physical demands that occur during OD match-play. Hence, BZ appears to provide players with a physical stimulus which is sufficient at replicating the absolute load of an entire OD match.

In regards to the physiological demands of spin bowlers, a greater physiological intensity was observed during BZ, as demonstrated by the higher $HR_{\text{mean}}$ (144 ± 9 b·min$^{-1}$) and time above 75%$HR_{\text{max}}$ (35 ± 27%) compared to the OD match format ($HR_{\text{mean}}$: 123 ± 19 b·min$^{-1}$; time above 75%$HR_{\text{max}}$: 15 ± 18%). Although, spin bowlers reported a slightly lower RPE following BZ (4.4 ± 0.8) than a OD match (4.9 ± 1.4). It is possible that the competitive environment of a typical cricket match rather than the BZ training setting may facilitate the observed increase in the perceived intensity of training reported by the spin bowlers in the current research. The results of Study 4 also demonstrated that BZ is a suitable format for the refinement of technical skill for spin bowlers, given that a greater number of deliveries relative to duration (85 ± 16 # balls·h$^{-1}$) were completed when compared to an entire OD match (37 ± 20 # balls). The combination of similar relative physical demands and the increased physiological and technical demands, particularly using the generic BZ scenario; of spin bowlers during BZ training advocates the use of this training format for the development and application of a match-appropriate TL for both conditioning and technical purposes.
Fielders

A common characteristic of fielding in cricket is the high proportion of the total distance at LI, and a long recovery period between HI efforts (Petersen et al., 2010; Rudkin & O’Donoghue, 2008). The current data demonstrated that during BZ, the majority of fielding was spent performing LI activities (82-84%) such as standing, walking and jogging, as is typical of a OD match. While fielders covered a greater overall distance during a OD match, they maintained a greater relative physical load during BZ. Of specific interest was that during generic BZ sessions (Study 2 and 4), there was a tendency for fielders to cover a slightly greater relative distance (BZ: 3462 ± 1525 m h⁻¹; OD: 3209 ± 1282 m h⁻¹) which also reflected a faster mean speed (BZ: 57 ± 25 m min⁻¹; OD: 47 ± 21 m min⁻¹) and a greater number of HI efforts (BZ: 80 ± 60 # h⁻¹; OD: 46 ± 33 # h⁻¹). The increased relative physical demand resulting from the generic BZ training sessions suggested it can present a physically demanding training program that replicates the absolute demands of a typical OD cricket match.

As expected, this increased physical demand from BZ led to an increase in physiological responses, with fielders reporting higher HR responses than that observed during match-play (Studies 3 and 4). In particular within Study 4, there was a considerably greater percentage of overall time spent working above 75%HRmax during a generic BZ session (35 ± 42%) as opposed to a OD match (15 ± 22%). The manipulation of BZ training constraints further increase HR in comparison to OD fielding, particularly when new playing rules were introduced (HRmean: 141 ± 16 b min⁻¹; time >75%HRmax: 41 ± 40%). Unfortunately, only Petersen et al. (2010) has previously examined the physiological responses
amongst cricket fielders during match-play. The current data demonstrate that
the intensity at which fielders performed at during BZ, exceeded that of elite T20
fielders (Petersen et al., 2010). When combined with the physical demand
experienced during BZ, fielders appear to gain a more than sufficient match-
appropriate TL.

Further to this, the technical skills of fielders were quantified by the relative
number of throws completed during both BZ training (Study 4: BZ: 30 ±
16 # throws h⁻¹) and a OD match (29 ± 20 # throws h⁻¹). As previously stated,
the use of SSG for the purposes of skills training has been subject to criticism in
the past (Gabbett et al., 2009). However, this data demonstrated that there was
no loss of opportunity during BZ for technical training when compared to match-
play. Furthermore, the use of BZ allowed fielders to gain a sense of match
awareness when in the field and anticipate where the ball may travel and the
optimal position to be in when fielding. Therefore, in addition to providing a
match-specific conditioning stimulus suitable for replicating the overall load of a
typical OD match, fielders may also receive a significant technical stimulus from
BZ training that provides a physiological stimulus for adaptation.

Wicketkeepers

Finally, the generic BZ format provided an appropriate TL for wicketkeepers
when compared to match demands. As has been reported for OD match-play
(Petersen et al., 2010), the wicketkeepers reported upon in Studies 3, 4 and 5
covered the lowest absolute (609 ± 250 m) and relative (1926 ± 773 m h⁻¹)
distance of all playing positions. Similar to this previous research,
wicketkeepers spent a large percentage of BZ training undertaking LI activity (88-95%), with only a small number of HI efforts completed (28 ± 20 # h\(^{-1}\)). When compared to the current match data and that of Petersen et al. (2010), wicketkeepers tended to display slightly greater physical demands through BZ training.

Again, the greater physical demands of BZ resulted in a higher physiological load experienced by wicketkeepers during BZ. Specifically, an increased cardiovascular response resulted from BZ training (HR\(_{\text{mean}}\): 145 ± 8 b min\(^{-1}\); time >75%HR\(_{\text{max}}\): 36 ± 24%) opposed to that of a OD match (HR\(_{\text{mean}}\): 131 ± 11 b min\(^{-1}\); time >75%HR\(_{\text{max}}\): 13 ± 18%), regardless of the scenario used. Other than Petersen et al. (2010), there is no previous information that has specifically examined the physiological demands associated with wicketkeeping. However, as suggested in Study 5, it is possible that this increase in physiological intensity results from the unique movements of wicketkeepers such as repetitive squatting and side-stepping, which may not be strongly reflected through GPS measurement. As with the other playing positions, the BZ environment also provided an opportunity for wicketkeepers to develop their technical skills which included catching, throwing, positioning and movement, along with a sense of match-awareness. Although given the unique technical skills of wicketkeeping, the current research was not able to provide insight into this particular aspect of cricket.


Summary

In order to improve performance, current training methods adopted by cricket coaches include isolated skill-oriented net-based sessions or game-based CW simulations training. Unfortunately, this series of studies indicated that compared to a typical OD cricket match, the intensity created by these traditional training methods is not sufficient to replicate an actual match. Specifically, whilst providing players with an environment similar to that of an actual match, the use of CW simulation training provided an inconsistent and inadequate physiological and physical training demand for all players. Therefore, this training format would be difficult to implement within the cricket team environment as a varied training response is likely to result within each individual playing position. By comparison, the use of TCT provided a more match-specific physiological and physical training demand for all playing positions, despite an inconsistent physiological and physical response being observed across all playing positions. The major advantage of TCT however, was the consistent increased technical demand placed upon all playing positions. Even when compared to a OD cricket match, a greater technical load was likely to result from TCT sessions regardless of playing position. However, the disadvantage of TCT is the lack of a cricket-specific match environment that enables skill transference. Therefore, a consistent, match-specific TL is likely to be achieved through the use of a training method which incorporates a conditioning and technical training response. Based on the overall results from the current series of studies, it appears that the development of BZ as a cricket training format provides a consistent and sufficient TL within a match-specific environment. While OD match play provided players with a significantly greater
absolute load, the relative demands of BZ tended to exceed that of a typical match. Beyond providing a suitable environment for the physical conditioning of cricket players, there was a high technical demand maintained through the use of BZ training. Therefore, the use of BZ may be of great benefit to cricket coaches looking to implement a match-specific and intensive training session, within a more manageable period of time.

**Prescription of Battlezone**

The results from this thesis provide coaches and athletes with detailed information on the physical, physiological and technical responses resulting from the use of game-based training, and in particular BZ. Collectively, these data demonstrated the usefulness of BZ as a cricket training format. Importantly, our results demonstrated that BZ replicates the intensity levels and physical demands of a typical OD match. Furthermore, the reported TL’s resulting from BZ appear similar to more conventional training methods, which is similar to findings from other sports (Dellal et al., 2008; Gabbett, 2006; Hill-Haas et al., 2009a). To ensure cricket players are placed under a sufficient TL, whilst also developing and maintaining their technical abilities, coaches are encouraged to apply the results of this thesis to their current training programs.

Based on the information presented within this thesis, there are several factors that coaches must consider when prescribing BZ training sessions.

Firstly, it is important to note that manipulating the BZ environment produces varied physical and physiological responses across different player positions. For example, Study 5 showed that a greater TL results from different BZ
scenarios. Past research has demonstrated that increased physical, physiological and technical demands are provided through changes to the field size, number of players involved and game rules (Casamichana & Castellano, 2010; Fanchini et al., 2011; Kelly & Drust, 2009; Owen et al., 2004). The present results suggest that cricket coaches planning to increase the physical conditioning load of players, particularly batsmen and wicketkeepers; should consider the addition of new playing rules when using BZ, given that there were increased running demands in these scenarios. Separately, a major disadvantage of TCT is the inability to create specific match scenarios for the purposes of improving a specific aspect of their game. With the use of BZ, cricket coaches can adjust the training environment to suit an individual player’s and overall team’s training objectives in a time efficient manner. For the purposes of improving technical skill, coaches may consider changing the size of the playing area or the number of fielders present on the field at any one time. Although research is yet to examine this, it could be suggested that by manipulating the BZ playing field, players may be forced to perform under fielder pressure similar to a match. The addition of new playing rules appears to provide a greater physical conditioning stimulus, particularly for batsmen and wicketkeepers. However, the BZ scenarios presented are only a limited number of formats that may provide a sufficient training stimulus for cricket players, and coaches need to determine which scenario is best suited to their training goals.

These data also demonstrated that superior technical demands are achieved from TCT sessions as opposed to more match-like training environments such as BZ or CW simulations. This increased technical volume during traditional,
net-based training may relate to the greater number of players which can participate in the session. A limitation of BZ is that only a limited number of players can participate due its match-specific nature on a reduced field size. Therefore, increasing the number of participants that can train at any one time will unsurprisingly increase the technical volume achieved. Previously, more technically-based training sessions have been linked with greater improvements in technical skill performance when compared to match-based training amongst elite volleyball players (Gabbett, 2008). However, evidence suggests that game-based training is equally effective at improving technical skill as structured, skill-based training (Chatzopoulos, Drakou, Kotzamanidou & Tsorbatzoudis, 2006; Turner & Martinek, 1999). Despite an increase in the overall technical volume during TCT, there was no difference in the quality of the technical skills performed as observed within Studies 2 or 4. Therefore, it is possible that great developments in technical skill can be achieved from the use of BZ, although this may involve increasing the duration of the BZ session. Further research however, is required to determine if long term improvements in technical skill can be gained from the use of BZ training.

Another important note is that although in most instances, similar physical and physiological demands were placed upon players using either BZ or TCT. The results of Studies 2 and 4 demonstrated that the latter provided a superior environment for developing technical skill, and as a result facilitated a greater technical TL. Therefore, it could be argued that the isolated use of BZ may not be sufficient at providing a holistic environment for developing a cricket player’s technical abilities. Unfortunately, TCT does not allow players to develop these
skills in the context of a match environment. As a result, it is suggested that best practice consists of a mix between the amount of fixed (i.e. net-based) and game-based (i.e. BZ) training can best improve the performance of cricket players.

To provide an even greater match-specific conditioning response, coaches could manipulate the duration of the BZ training session, given that cricket is typically played of varying durations. For example, to replicate the physical demands of a complete OD match, coaches may want to consider increasing the batting duration during BZ beyond that of this thesis. This may be useful for use in the pre-competition phase of a season in which coaching staff are aiming to improve the physical fitness levels of their players. Increasing the duration of the BZ session will obviously influence the volume of technical load achieved by the players. However due to time constraints or availability of facilities, increases to the duration of a BZ training session for the purposes of improving technical skill may not always be possible. As such, it is recommended that coaches use both training formats to ensure players are provided with a well-rounded TL which encompasses physical conditioning, technical skill and match awareness. It was however beyond the scope of this research to determine the precise volume of each training format.

Coaches should also consider that regardless of the scenario, BZ may be more suitable for training for the shorter cricket formats (OD and T20 matches). This finding reflects the HI at which players performed during BZ, and its similarity to these shorter cricket formats. Furthermore, the ease at which the BZ
environment can be manipulated allows coaches to create match scenarios similar to that of a limited overs (e.g. OD or T20) match. The use of BZ may also have benefits as a more time-efficient training method. The results of Studies 2 and 4 demonstrated that a greater TL results from match-specific training as opposed to TCT methods, despite a similar training duration. Although the duration of the training session is ultimately decided by the coaching staff they may choose to use BZ when time is limited such as during long tournaments or when touring opposing countries. In using BZ coaches can be confident that a match-appropriate TL can be achieved in a shorter period of time. This may also lend BZ to being a practical method for warm-up sessions prior to a match.

**Reliability of BZ**

The physical and physiological demands of BZ and prescription of its use have been previously outlined. However, in planning an effective training program, coaches also need to ensure that the TL provided through various training formats is suitable and consistent. Therefore, this thesis also aimed to report on the reliability of BZ. Past research has demonstrated that the specific physiological and physical responses of SSG are repeatable (Hill-Haas et al., 2008b; Rampinini et al., 2007). However, given the novelty of this research, it remained to be established if the physical and physiological demands of BZ were consistent. The data from Study 3 demonstrated that BZ largely provided a reliable training stimulus in cricket players. Specifically, physiological measures (with the exception of \([\text{BLa}^-]\) and percentage of time within HR Zones 2 and 4 amongst medium-fast bowlers) were consistent between the two
generic BZ sessions for each playing position. Additionally, the peak %HR_{max} achieved with each playing position demonstrated an acceptable level of variability (CV: 6-8%). The cardiovascular load experienced during BZ appears consistent between training sessions. This supports Rampinini et al. (2007) who had previously demonstrated that the %HR_{max} achieved was also reproducible between soccer SSG training (CV: 2.8-5.4%). In addition, both Rampinini et al. (2007) and Hill-Haas et al. (2008b) have demonstrated that other perceptual and physiological measures such as RPE (CV: 6.2-31.9%) and [BLA] (%TE: 2-35%) are not reproducible either between or within small-sided soccer games training sessions. Importantly, these measures also demonstrated poor levels of reliability following generic BZ training (CV: RPE: 19.9-24.4%; [BLA]: 23.5-25.8%). This suggests that the amount of anaerobic work completed in the final stages of the bout is highly variable. Despite this, the data demonstrated that BZ provides consistent cardiovascular response that allows conditioning coaches to prescribe a consistent TL for each session.

Study 3 also demonstrated that physical measures of performance during generic BZ session displayed varying levels of reproducibility. Both total distance and mean speed reported high levels of reliability (CV: 4.9-16.3% and 6.7-9.4%, respectively). However, this was not the case for the number of HI efforts completed per session (CV: 52.5-114.3%). This greater variability in measures of HI activity is similar to the available data that has reported on cricket match-play. Similarly, Hill-Haas et al. (2008b) reported that the total distance completed at >18 km·h^{-1} during soccer SSG was highly variable (%TE: 38-51%). It is possible the poor reliability of the GPS devices during high-speed
running may be reflected in the high variability of the HI activity between BZ sessions as in Hill-Haas et al. (2008b). However, this variability may also reflect the nature of self-selected movements/motions during BZ session, which may be influenced through placement of the ball by both bowlers and batsmen during play. However, due to the similarity in the total distance covered and average speed of each BZ session, coaches are able to prescribe a consistent physical TL using BZ. The reliability of both physiological and physical measures during generic BZ suggests that it provided more training benefits than simply the technical skill and decision-making transference that was originally intended by Renshaw and colleagues (2010). Although, the reproducibility of the technical skills (number of balls faced, percentage of good contacts, number of deliveries completed, accuracy of deliveries, number of throws) during generic BZ training sessions are yet to be examined, they are highly relevant to overall performance of cricket players.

**Suggested Training Model for Battlezone**

Similar to previous studies which have examined the use of SSG (Dellal et al., 2011a; Hill-Haas et al., 2009b), the results of this thesis provided the basis for a BZ training model to be put forward (as displayed in Figure 8.1 over the page). A similar model has previously been proposed to guide the prescription in soccer (Hill-Haas, 2009). This model aims to allow coaches to develop training with an understanding of the various factors that are likely to affect the training outcomes for cricket training using BZ.
Figure 8.1: Factors affecting training outcomes with Battlezone.

Conclusion

As demonstrated by the current findings, the use of more traditional training methods such as net-based sessions and CW practice may not provide players with a completely sufficient match-appropriate TL. Overall neither training format elicited a more physically and physiologically demanding environment for any individual playing position. Rather, this was specific to each position. However, the evidence demonstrates that TCT allows for a greater technical demand to be achieved. As a result, the use of a more match-specific training environment which encompasses all aspects of cricket training (conditioning and skill development) was recommended. The findings presented in this thesis demonstrate and advocate the use of game-based training, such as BZ as a
valid and reliable training method for cricket. Importantly, the present data demonstrated that BZ provides sufficient physical, physiological and technical demands, that are typical of a OD cricket match. Further to this, the current data also suggested that the internal and external TL’s imposed on cricket players can be manipulated to achieve specific responses (e.g. increase conditioning status, improve technical ability, create match awareness) through the creation of varying BZ scenarios. In addition to this, BZ training appears to provide a superior TL for physical conditioning as opposed to traditional forms of cricket training (e.g. net-based sessions, fielding-specific drills, CW simulations). The data also suggested that greater technical demands are placed upon players during more traditional training methods. However, the technical demands resulting from BZ training still exceed that of a typical OD match and therefore, provide a match-specific technical stimulus. Overall, the current findings suggested that BZ is a suitable method for reproducing the demands typically experienced during a OD cricket match. In addition, it provides a match-specific environment that enables the development of technical abilities, decision-making and match awareness skills, as originally intended.
Chapter 9

Summary and Conclusion
Summary of the Major Findings

The following section provides a summary of each specific study that was completed throughout this research project. Table 9.1 (pages 224-225) outlines the physical, physiological and technical demands of cricket players during each training format.

Study 1 – Accuracy and Reliability of GPS Monitoring during Sport-Specific Activities

The initial study of this thesis aimed to determine the accuracy of a range of GPS devices during movements typical of cricket and other FBTS. The findings demonstrated that when compared to a criterion measure (VICON), the GPS devices reported significantly similar distance and speed measures, particularly during cricket-specific movements. However, there was a tendency for the GPS devices to underreport the distances covered and speeds reached during these movements in comparison to VICON. In addition to this, the results also showed that regardless of the movements performed, the GPS devices possessed a low to moderate level of reliability, again particularly during the cricket-specific movements. Collectively, these data indicated that GPS devices were moderately reliable, despite consistently underreporting measures of distance and speed. With this knowledge of the limitations of GPS devices, they could be used to obtain information during match-play and training specific for cricket purposes.
Study 2 – Physiological, Physical and Technical Demands of Cricket Players during, Traditional Cricket Training, Centre-Wicket Simulation and Match-Play

The second study quantified and compared the physiological, physical and technical demand of cricket players during TCT sessions, CW game-simulations and competitive OD matches. The data demonstrated that the associated demands were unique to each playing position. However, regardless of the playing position, these data demonstrate that greater physiological and physical demands resulted from TCT sessions when compared to CW simulations. An important finding was that CW simulations failed to replicate the intensity of OD match-play. In contrast, the demands of TCT sessions typically exceeded that of a OD match. The technical demands of players during TCT, again regardless of playing position, exceeded those measured during both CW simulation sessions and OD matches. These findings demonstrated that the use of CW simulations training failed to provide a sufficient and match-specific TL for each playing position within elite cricket players. It was observed that TCT methods such as net-based sessions and skill-specific drills may actually provide players with a more match-intensive training environment. However, the transference of technical skill and match awareness developed by these methods may be limited given the absence of a match environment.

Study 3 – The Physiological Responses and Physical Demands of Cricket Players and the Reproducibility of Battlezone

The third study introduced the use of BZ and aimed to quantify the physiological and physical demands of cricket players of BZ. Additionally, this study also
determined the reproducibility of the demands imposed by BZ. The results observed that regardless of playing position, moderate to high physiological and physical demands were imposed during a generic BZ session. However, these demands were specific for each individual playing position. As such, batsmen and medium-fast bowlers performed at the greatest physical (total distance, mean speed and number of HI efforts) and physiological (HR_{mean}, % time >75\%HR_{max}) intensities during generic BZ sessions when compared to the other playing positions. The results also indicated that the physical and physiological responses of players during BZ were reproducible, with the exception of the number of HI efforts performed, [BLa'] and RPE (CV >5\%). This study also suggested that a greater TL was imposed during a generic BZ training session than the previously observed CW simulations, regardless of playing position. Therefore, the use of BZ as a cricket training method appears to provide a more match-specific training environment.

**Study 4 – Physiological, Physical and Technical Demands of Cricket Players during Battlezone, Traditional Cricket Training and Match-Play**

The penultimate study compared the physiological, physical and technical demands of amateur cricket players of BZ, TCT sessions and OD cricket matches. These data demonstrated that the demands of cricket match-play was either replicated or exceeded during both BZ and TCT sessions. While these responses varied across playing positions, BZ demonstrated greater physiological (peak %HR_{max}, HR_{mean}, % time >85\%HR_{max}, [BLa'], RPE) and physical (total relative distance covered, mean speed, relative number of HI
Table 9.1: Summary of the physical, physiological and technical demands of amateur cricket players during Battlezone and Traditional cricket training (mean ± SD).

<table>
<thead>
<tr>
<th>Playing Position</th>
<th>Training Format</th>
<th>Total Distance (m h⁻¹)</th>
<th>HI Activity Distance (m h⁻¹)</th>
<th>Work-to-Rest Ratio (1:x)</th>
<th>HR_{mean} (b min⁻¹)</th>
<th>Time &gt;75%HR_{max} (%)</th>
<th>RPE (AU)</th>
<th>Balls Faced (# h⁻¹)</th>
<th>Balls Bowled (# h⁻¹)</th>
<th>Throws (#h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batsman</td>
<td>Generic BZ</td>
<td>3856 ± 910</td>
<td>992 ± 406</td>
<td>18 ± 9</td>
<td>164 ± 12</td>
<td>65 ± 42</td>
<td>4.9 ± 1.4</td>
<td>82 ± 18</td>
<td>78 ± 14</td>
<td>9 ± 5</td>
</tr>
<tr>
<td></td>
<td>Field Size</td>
<td>3561 ± 618</td>
<td>934 ± 470</td>
<td>19 ± 8</td>
<td>153 ± 12</td>
<td>70 ± 49</td>
<td>5.5 ± 1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Player Number</td>
<td>3231 ± 270</td>
<td>679 ± 223</td>
<td>21 ± 8</td>
<td>156 ± 14</td>
<td>72 ± 56</td>
<td>5.2 ± 2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field Size-Player Number</td>
<td>3500 ± 380</td>
<td>931 ± 305</td>
<td>17 ± 6</td>
<td>147 ± 13</td>
<td>52 ± 45</td>
<td>4.5 ± 1.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rule Changes</td>
<td>3396 ± 412</td>
<td>974 ± 415</td>
<td>12 ± 3</td>
<td>158 ± 17</td>
<td>71 ± 59</td>
<td>7.4 ± 1.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TCT</td>
<td>560 ± 470</td>
<td>4 ± 15</td>
<td>779 ± 865</td>
<td>153 ± 15</td>
<td>57 ± 60</td>
<td>4.5 ± 1.2</td>
<td>303 ± 26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium-Fast Bowler</td>
<td>Generic BZ</td>
<td>4320 ± 1284</td>
<td>777 ± 300</td>
<td>35 ± 30</td>
<td>152 ± 32</td>
<td>53 ± 27</td>
<td>5.7 ± 1.3</td>
<td>78 ± 14</td>
<td>9 ± 5</td>
<td></td>
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<tr>
<td></td>
<td>Field Size</td>
<td>4124 ± 1607</td>
<td>612 ± 505</td>
<td>22 ± 12</td>
<td>145 ± 11</td>
<td>62 ± 34</td>
<td>4.7 ± 1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Player Number</td>
<td>4707 ± 1604</td>
<td>748 ± 574</td>
<td>16 ± 8</td>
<td>174 ± 13</td>
<td>71 ± 53</td>
<td>5.7 ± 1.1</td>
<td></td>
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<tr>
<td></td>
<td>Field Size-Player Number</td>
<td>5206 ± 1325</td>
<td>829 ± 487</td>
<td>20 ± 8</td>
<td>148 ± 9</td>
<td>50 ± 36</td>
<td>5.1 ± 0.9</td>
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<td></td>
<td>Rule Changes</td>
<td>3622 ± 1027</td>
<td>577 ± 415</td>
<td>23 ± 20</td>
<td>147 ± 15</td>
<td>50 ± 60</td>
<td>6.0 ± 2.2</td>
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<td></td>
<td>TCT</td>
<td>4249 ± 1125</td>
<td>1090 ± 459</td>
<td>21 ± 33</td>
<td>147 ± 31</td>
<td>54 ± 59</td>
<td>5.2 ± 1.2</td>
<td>90 ± 11</td>
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<tr>
<td>Spin Bowler</td>
<td>Generic BZ</td>
<td>2923 ± 632</td>
<td>244 ± 170</td>
<td>97 ± 62</td>
<td>152 ± 19</td>
<td>39 ± 31</td>
<td>4.8 ± 0.9</td>
<td>85 ± 16</td>
<td>14 ± 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Player Number</td>
<td>3831 ± 104</td>
<td>484 ± 403</td>
<td>46 ± 35</td>
<td>132 ± 6</td>
<td>12 ± 16</td>
<td>3.0 ± 0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field Size-Player Number</td>
<td>2906 ± 116</td>
<td>325 ± 345</td>
<td>111 ± 114</td>
<td>162 ± 5</td>
<td>89 ± 42</td>
<td>5.5 ± 0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rule Changes</td>
<td>2967 ± 461</td>
<td>145 ± 73</td>
<td>58 ± 30</td>
<td>131 ± 5</td>
<td>8 ± 4</td>
<td>4.0 ± 1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TCT</td>
<td>3419 ± 951</td>
<td>209 ± 332</td>
<td>231 ± 278</td>
<td>143 ± 16</td>
<td>36 ± 35</td>
<td>5.2 ± 1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9.1 (cont'd): Summary of the physical, physiological and technical demands of amateur cricket players during Battlezone and Traditional cricket training (mean ± SD).

<table>
<thead>
<tr>
<th>Playing Position</th>
<th>Training Format</th>
<th>Total Distance (m·h⁻¹)</th>
<th>H1 Activity Distance (m·h⁻¹)</th>
<th>Work-to-Rest Ratio (1:x)</th>
<th>HR_{mean} (b·min⁻¹)</th>
<th>Time &gt;75%HR_{max} (%)</th>
<th>Throws (#h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fielder</td>
<td>Generic BZ</td>
<td>3462 ± 1525</td>
<td>525 ± 435</td>
<td>46 ± 40</td>
<td>137 ± 26</td>
<td>25 ± 29</td>
<td>30 ± 16</td>
</tr>
<tr>
<td></td>
<td>Field Size</td>
<td>4046 ± 1392</td>
<td>621 ± 426</td>
<td>41 ± 32</td>
<td>133 ± 13</td>
<td>20 ± 25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Player Number</td>
<td>3996 ± 1670</td>
<td>580 ± 537</td>
<td>35 ± 16</td>
<td>134 ± 19</td>
<td>28 ± 43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field Size-Player Number</td>
<td>3703 ± 1488</td>
<td>522 ± 380</td>
<td>39 ± 22</td>
<td>129 ± 20</td>
<td>20 ± 36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rule Changes</td>
<td>4063 ± 1253</td>
<td>658 ± 473</td>
<td>23 ± 17</td>
<td>141 ± 16</td>
<td>41 ± 40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TCT</td>
<td>3650 ± 724</td>
<td>548 ± 446</td>
<td>42 ± 30</td>
<td>138 ± 10</td>
<td>33 ± 22</td>
<td>49 ± 9</td>
</tr>
<tr>
<td>Wicketkeeper</td>
<td>Generic BZ</td>
<td>2099 ± 862</td>
<td>155 ± 105</td>
<td>134 ± 72</td>
<td>154 ± 11</td>
<td>31 ± 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field Size</td>
<td>1815 ± 972</td>
<td>110 ± 154</td>
<td>238 ± 143</td>
<td>144 ± 3</td>
<td>49 ± 16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Player Number</td>
<td>1639 ± 568</td>
<td>90 ± 96</td>
<td>188 ± 97</td>
<td>151 ± 11</td>
<td>35 ± 38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field Size-Player Number</td>
<td>2152 ± 937</td>
<td>93 ± 64</td>
<td>189 ± 80</td>
<td>129 ± 4</td>
<td>5 ± 3</td>
<td></td>
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<tr>
<td></td>
<td>Rule Changes</td>
<td>1926 ± 528</td>
<td>223 ± 151</td>
<td>55 ± 12</td>
<td>145 ± 9</td>
<td>58 ± 34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TCT</td>
<td>2303 ± 694</td>
<td>326 ± 285</td>
<td>72 ± 49</td>
<td>141 ± 16</td>
<td>35 ± 30</td>
<td></td>
</tr>
</tbody>
</table>
efforts) demands than either TCT or a typical OD cricket match. However, batsmen achieved a greater technical stimulus (# balls faced, # balls hit, and % good contact shots) from performing traditional net-based training sessions as opposed to BZ. Within the other playing positions (medium-fast bowlers, spin bowlers, fielders and wicketkeepers), neither training method produced a superior physiological, physical or technical demand compared to a OD cricket match. Therefore this data demonstrated that the use of BZ provides a more match-appropriate TL than CW simulations, regardless of playing position. As a result, the use of BZ as a training method may be more beneficial for certain players, particularly batsmen, given its highly physical, physiological and technical.

Study 5 – The Effect of Rule Modifications and Changes to the Playing Environment on the Physiological Responses and Physical Demands of Cricket Players during Battlezone

The final study examined the effect of rule modifications, player numbers and playing field size on the physical demands and physiological responses during BZ. Specific physical and physiological responses within each playing position resulted from modifications to the BZ training environment (player number, field size, player number and field size, rule changes). Changes made to the BZ playing rules (i.e. ‘hit and run’, alternating ball delivery and return throws to the wicketkeeper) produced the greatest changes in physical demands (mean speed, relative sprinting distance, work-to-recovery ratio) and physiological responses (peak %HR_max, % time >75%HR_max, RPE), particularly within the batsmen and wicketkeepers. By comparison, modifications to the number of
fielders and the size of the BZ playing area had only a minor influence on training intensity. The use of the rule changes scenario appeared to invoke the greatest conditioning response, whereas changes to the number of players and field size were more likely to allow for technical skill development. Therefore, this information allows coaches to plan their training program to provide specific training responses that are tailored to the primary objective of the training session.

Practical Applications

This series of studies provides several important practical applications for coaches and practitioners involved in the development and implementation of cricket training including:

- The current GPS devices used by coaches appear to consistently underreport the measurement of the external loads of cricket players. However it is recommended that players wear the same device during data collection periods to allow for any inter-unit variability.

- Although the use of CW simulations training provides a match-like environment, the imposed TL’s are not reflective of match demands. This may make it difficult for coaches to implement CW simulations successfully into training programs to provide a match-specific training response. The use of modified game-based scenario training in the form of cricket SSG (BZ) may be beneficial at providing a match-specific training response.

- A generic BZ training scenario places a moderate to high physical and physiological demand on players, regardless of playing position. As a
result, coaches can develop an effective cricket-specific conditioning program using BZ, as it provides superior physical conditioning and technical development stimuli to TCT.

- BZ sessions also provide a consistent internal and external TL to cricket players allowing players to gain a consistent training response through repeated BZ use.

- The greater relative physical and physiological demand of BZ in comparison to an OD match allows coaching staff to provide a demanding training stimulus that replicates an actual cricket match, within a shorter time frame. As a result this would provide more opportunity for other forms of training to occur (e.g. strength training, rehabilitation) or provide greater rest period between matches and training.

- Both generic BZ and TCT sessions are sufficient at providing a match-intensive training environment. It is important for coaches to consider the advantages of each training format to determine which format might be best suited to the desired training goal. It is also suggested that the concurrent use of BZ and TCT methods may provide the best combination of cricket-specific conditioning and technical training.

- The use of different BZ scenarios presents coaches with the option of implementing BZ sessions either at different time points in the annual periodisation plan or to target specific cricket outcomes. For example, specific manipulations of BZ rules resulted in a significant increase in the running demands of players. This may either provide a greater physical
conditioning stimulus or allow players to rehearse typical cricket motions and skills under fatigue that is more representative of match play.
Recommendations for Future Research

Despite the stated outcomes of this thesis, continued research is required to further understand the physical and physiological demands associated with cricket and cricket training. As highlighted throughout this review, there is limited information available regarding the physical and physiological responses of cricket players during either match-play or training to help guide training prescription. The current research provides valued information of the demands associated with game-based SSG training (i.e. BZ) in cricket. Future studies need to compare the training adaptation (physical, physiological and technical) that can be achieved either using game-based training or TCT. Furthermore, it needs to be established if players are able to transfer the skills learnt through game-based training such as BZ, into a competitive match to improve performance.

By understanding these responses, coaches can develop individualised training programs that may provide greater conditioning or technical responses depending on the training goal. Due to the limited research available on this topic, the specific training responses or TL dosage that can be applied through specific BZ scenarios requires further research. Future research needs to be completed to determine which BZ scenarios are the most effective for different factors relating to cricket such as playing position, skill level, time of season and training outcome.

Lastly, much research has also been conducted on the prevalence of injuries which occur within cricket players (Dennis et al., 2003; Dennis et al., 2005;
Finch, Elliott & McGrath, 1999; Finch, White, Dennis, Twomey & Hayen, 2009; Gregory, Batt & Wallace, 2002, 2004; Orchard, James, Portus, Kountouris & Dennis, 2009; Stretch, 2001). To date, studies reporting on the incidence of cricket-related injuries, particularly within medium-fast bowlers; conclude that these injuries are linked to a player’s bowling technique and overuse (Elliot, Burnett, Stockill & Bartlett, 1996). Previous research has demonstrated a lower incidence of training injuries during game-based training when compared to traditional conditioning activities within rugby league (Gabbett, 2002). However, no information exists detailing the correlation between game-simulation training such as BZ, and the likelihood of incurring cricket-related injuries. This should be explored in future research that continues to report on BZ training.
Chapter 10

References


Appendix A

Information Statement and Consent Form (Study 1)
Information Statement for the Research Project:

The accuracy and reliability of 10 Hz GPS units and radio frequency tracking units during sports-specific movements

Document Version 2; dated 03/08/2010

You are invited to participate in the research project identified above which is being conducted by Mr William Vickery and Dr Ben Dascombe from the School of Environmental and Life Sciences at the University of Newcastle. The research is part of William Vickery’s studies at the University of Newcastle, supervised by Ben Dascombe from the School of Environmental and Life Sciences.

**Why is the research being done?**

At the current point in time only a small number of studies have detailed 1 and 5 Hz GPS units however, no data exists regarding the newer 10 Hz units or radio frequency (RF) tracking devices. As GPS is now an integral part of elite sport in assessing training and match-play, this study aims to provide information on the accuracy and reliability of MinimaxX GPS (10 Hz) units as well as a new radio frequency tracking units system developed by the AIS. It is expected that this updated technology will provide relevant and appropriate information to both coaching staff and athletes to help in the construction of conditioning and recovery programs.
Who can participate in the research?

We are seeking a participant with a (at the very least) moderate fitness level with some experience in short sprints to participate in this research.

To be eligible for the study, the volunteer must:

- Be physically active and involved in regular exercise
- Be a willing volunteer to participate in the project
- Not have had any recent long term illness or injury that prevents you from completing numerous sprint protocols
- Have sufficient vision (particularly at night)

What choice do you have?

Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate, your decision will not disadvantage you. If you do decide to participate, you may withdraw from the project at any time without giving a reason and have the option of withdrawing any data which identifies you.

What would you be asked to do?

If you agree to participate, you will be asked to complete the following questionnaires and testing protocols:

Pre Exercise Health Screening Questionnaire

The purpose of the Pre-Exercise Health Screening Questionnaire (see Appendix C) is to ensure you do not have any current or previous health issues which may place you at a risk of injury. The questionnaire was developed by Sports Medicine Australia and is an industry accepted form to ensure the safety of exercise participants.

All subjects participating in the study will be required to complete the questionnaire. This will be done prior to beginning of the testing sessions. After completing the questionnaire, you will be advised if you will be able to participate in the study or if you will require additional assessment from a general practitioner. If they allow you to complete the study, you will be included, however, if you have been advised not to perform any high intensity activities or you have poor vision, particularly at night you will not be included in this study.
Testing Session Data Collection

This will occur at during the night (as it needs to be completely dark) over two consecutive nights. During both testing sessions you will be required to perform a simulated sports protocol whilst wearing small monitors (GPS and RF units) which will not interfere with your ability to participate in physical activity. More detail on the protocols is provided below:

- ** Cricket:**
  - Run-a-three test: this involves sprinting three times over a short distance and turning 180° at the end of each sprint whilst carrying a cricket bat
  - Bowling Run-up: this involves sub maximal sprint (mimicking a fast bowlers run-up) over s short distance and then walking back to the starting position
  - Fielding: will involve walking a short distance and then sprinting to a marker placed at various positions and then walking back to the starting position

- ** Tennis:**
  - Slow jogging around a half court
  - Fast running around a half court
  - Moving side to side from the centre line
  - Randomly moving around the half court and various speeds and distances

- **Repeated Sprints:**
  - Involves sprinting over a short distance with small rest periods between each sprint

- **Team Sports Activity:**
  - Short maximal sprints
  - Agility movements and drills
  - Simulation of Random movements for 6 seconds around the baseline

- **Football:**
  - 15 metre maximal sprints with 30 seconds recovery between each sprint
  - 25-m efforts with change of direction at jogging, running and sprinting speeds
  - Match specific activities.
  - 25-m efforts with tighter change of direction at jogging running and sprinting speeds

- **Motion Analysis:**
  - You be wearing a Minimax Global Positioning System (GPS) monitor during the testing sessions. The GPS monitor provides information on the intensity and distance covered that you will cover across the sessions.
  - You will be required to wear a radio frequency tracking system (RF) during the testing sessions, which will be recorded via receivers surrounding the testing area.
• Video Analysis (VICON):
  o You will be videoed across each trial using a three dimensional VICON camera system to allow for an accurate measure of the activities.

_How much time will it take?_

Testing session data collection will occur during the night time (over two consecutive nights), once it is completely dark. The duration of the testing session should not last more than two hours, equating to a total of approximately four hours.

_What are the risks and benefits of participating?_

During testing you will be required to perform maximal intensity exercise which may cause some discomfort. You will be pre-screened to ensure that you do not have any existing medical conditions that may place you at risk of injury when undertaking this exercise. You will be referred to a general practitioner to obtain approval if an existing medical condition is present.

The GPS and RF devices measure slightly less than 90 x 45 x 25mm, and weigh approximately 75g each. When worn in a performance undergarment, the GPS and RF device is non-invasive to your regular movements. You may initially have a loose awareness of the GPS device, which will diminish following a familiarisation period. The GPS and RF device will have no effect on your performance.

_How will your privacy be protected?_

The confidentiality of this study is assured. Under no circumstances will any names appear on publications associated with this research. The individual results will be provided to you in verbal and written form with no one else being given the results unless you request it. Hard copies of results will be stored in a locked filing cabinet along with backed up data stored securely in the filing cabinet. The researchers are the only personnel who have access to the data. Your confidentiality will be ensured by replacing your name with a numerical code. The data will be retained for a minimum of five (5) years, at the University of Newcastle. This is in accordance with the University of Newcastle Research Data and Materials Management Policy.
How will the information collected be used?

Data will be presented in scientific journals and in a thesis to be submitted for Mr William Vickery’s degree. At the conclusion of the data collection, a summary will be presented to the participant and no personal information will be included in these summaries. Each match will be videotaped for a more detailed analysis of simulated sports activities. You will be able to view the tape at any time to review the recording and edit or erase your contribution.

What do you need to do to participate?

Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, contact the researcher.

If you would like to participate, please complete the attached pre-exercise health screening questionnaire and the consent form. This will be collected immediately.

If you are a suitable participant for this study, you will be contacted within three (3) days to confirm your inclusion in this study. If the pre-exercise health screen has identified any medical contraindications, you will be required to seek a medical clearance before being included in the study.

Further information

If you would like further information please contact William Vickery and/or Ben Dascombe for further information regarding the study.

William Vickery

Phone: (02) 4932 3632
Mobile: 0407 323 634
Email: William.Vickery@newcastle.edu.au
Ben Dascombe

Phone: (02) 4348 4150
Mobile: 0417 712 381
Email: Ben.Dascombe@newcastle.edu.au

Thank you for considering this invitation.

Dr Ben Dascombe  Mr William Vickery
Project Supervisor  PhD Student

Complaints about this research

This project has been approved by the University's Human Research Ethics Committee, Approval No. H-H-2010-1173

Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Office, The Chancellery, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone (02) 49216333, email Human-Ethics@newcastle.edu.au.
Consent Form for the Research Project:

The reliability and accuracy of 10 Hz GPS units and radio frequency tracking units during sports-specific movements

Document Version 1; dated 25/06/2010

I agree to participate in the above research project and give my consent freely.

I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.

I understand that the purpose of this study is to determine the accuracy and reliability of 10Hz GPS units and radio frequency tracking units when monitoring specific movement patterns.

I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing.

I consent to:

- Undergo pre-screening procedures that involve a health questionnaire and the collection of personal details
- Wear Minimaxx GPS devices whilst completing a range of sport-specific movements that are related to sports such as Tennis, Cricket and Football.
- Wear radio frequency tracking units (AIS, Australia) whilst completing a range of sport-specific movements that are related to sports such as Tennis, Cricket and Football.
- Appearing on video to be used by the researchers.
I understand that participation in the research will expose participants to those risks associated with sport specific movements.

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: __________________________________________________________

Signature: __________________________________ Date: ___________
Appendix B

Human Research Ethics Approval (Study 1)
HUMAN RESEARCH ETHICS COMMITTEE

Notification of Expedited Approval

To Chief Investigator or Project Supervisor: Doctor Benjamin Dascombe
Co-Investigators / Research Students: Mr William Vickery
Re Protocol: Reliability and Accuracy of the new 10Hz Minimak GPS units and Radio Frequency Tracking Units
Date: 12-Aug-2010
Reference No: H-2010-1173
Date of Initial Approval: 11-Aug-2010

Thank you for your Response to Conditional Approval submission to the Human Research Ethics Committee (HREC) seeking approval in relation to the above protocol.

Your submission was considered under Expedited review by the Chair/Deputy Chair.

I am pleased to advise that the decision on your submission is Approved effective 11-Aug-2010.

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research, 2007, and the requirements within this University relating to human research.

Approval will remain valid subject to the submission, and satisfactory assessment, of annual progress reports. If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.

The full Committee will be asked to ratify this decision at its next scheduled meeting. A formal Certificate of Approval will be available upon request. Your approval number is H-2010-1173.

If the research requires the use of an Information Statement, ensure this number is inserted at the relevant point in the Complaints paragraph prior to distribution to potential participants. You may then proceed with the research.

Conditions of Approval

This approval has been granted subject to you complying with the requirements for Monitoring of Progress, Reporting of Adverse Events, and Variations to the Approved Protocol as detailed below.

PLEASE NOTE:
In the case where the HREC has “noted” the approval of an External HREC, progress reports and reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, or a Renewal of approval, you will apply to the External HREC for approval in the first instance and then Register that approval with the University’s HREC.

- Monitoring of Progress
Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. A progress report is required on an annual basis. Continuation of your HREC approval for this project is conditional upon receipt, and satisfactory assessment, of annual progress reports. You will be advised when a report is due.

- **Reporting of Adverse Events**

1. It is the responsibility of the person first named on this Approval Advice to report adverse events.
2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
3. Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Approval Advice to the (HREC) by way of the Adverse Event Report form within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
4. Serious adverse events are defined as:
   - Causing death, life threatening or serious disability.
   - Causing or prolonging hospitalisation.
   - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
   - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
   - Any other event which might affect the continued ethical acceptability of the project.
5. Reports of adverse events must include:
   - Participant's study identification number;
   - Date of birth;
   - Date of entry into the study;
   - Treatment arm (if applicable);
   - Date of event;
   - Details of event;
   - The investigator's opinion as to whether the event is related to the research procedures; and
   - Action taken in response to the event.
6. Adverse events which do not fall within the definition of serious or unexpected, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.

- **Variations to approved protocol**

If you wish to change, or deviate from, the approved protocol, you will need to submit an Application for Variation to Approved Human Research. Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. Variations must be approved by the (HREC) before they are implemented except when Registering an approval of a variation from an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

**Linkage of ethics approval to a new Grant**

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.

Best wishes for a successful project.
Professor Alison Ferguson
Chair, Human Research Ethics Committee

For communications and enquiries:
Human Research Ethics Administration

Research Services
Research Office
The University of Newcastle
Callaghan NSW 2308
T +61 2 492 18999
F +61 2 492 17164
Human-Ethics@newcastlive.edu.au

Linked University of Newcastle administered funding:

<table>
<thead>
<tr>
<th>Funding body</th>
<th>Funding project title</th>
<th>First named investigator</th>
<th>Grant Ref</th>
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Appendix C

Information Statement and Consent Form (Studies 2-5)
Information Statement for the Research Project:

Physiological and perceptual responses and movement characteristics of cricket players during Battlezone

Document Version 2; dated 17/12/2010

We have asked your club secretary to distribute this invitation in the research project identified above which is being conducted by Mr William Vickery (PhD Student) and Dr Ben Dascombe from the School of Environmental and Life Sciences at the University of Newcastle. The research is part of William Vickery’s studies at the University of Newcastle, supervised by Ben Dascombe from the School of Environmental and Life Sciences

Why is the research being done?

Previous research has demonstrated that small sided games can produce similar physiological and perceptual responses to traditional training and conditioning approaches as well as enhanced skill development. In the sport of cricket a new training technique known as ‘Battlezone’ is being used in the elite setting. This training technique is similar to the small sided soccer games in that field size, player numbers and rules are manipulated to elicit specific responses during a simulated match. However at the current point in time no research has been published regarding the physiological and perceptual responses and time-motion characteristics of small sided cricket games (Battlezone). This study aims to examine the physiological and perceptual responses and time-motion characteristics associated with Battlezone. It is envisioned that conditioning
coaches may use the results of this study to plan game-specific conditioning programs for cricket players.

**Who can participate in the research?**

To be eligible for the study, volunteers must:

- Be a willing volunteer to participate in the project
- Be currently playing in a regular cricket competition
- Be able to commit to an extended period of testing
- NOT have had any recent long term illness or injury that prevents you from completing numerous cricket activities
- Completed a written informed consent form
- Completed and passed a health screening questionnaire

**What choice do you have?**

Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate, your decision will not disadvantage you. If you do decide to participate, you may withdraw from the project at any time without giving a reason and have the option of withdrawing any data which identifies you.

**What would you be asked to do?**

If you agree to participate, you will be asked to complete the following questionnaires and testing protocols:

*Pre Exercise Health Screening Questionnaire*

The purpose of the Pre-Exercise Health Screening Questionnaire (see Appendix C) is to ensure you do not have any current or previous health issues which may place you at a risk of injury. The questionnaire was developed by Sports Medicine Australia and is an industry accepted form to ensure the safety of exercise participants.

All subjects participating in the study will be required to complete the questionnaire. This will be done prior to beginning of the testing sessions. After completing the questionnaire, you will be advised if you will be able to participate in the study or if you will require additional assessment from a general practitioner. If they allow you to complete the study, you will be included, however, if you have been advised not to perform any high intensity activities, you will not be included in this study.
Testing Session Data Collection

Testing sessions will take place during the regular cricket season between October and February. During all testing sessions you will be required to participate in a new cricket training technique known as Battlezone, whilst numerous physiological, perceptual and time-motion measurements are taken. More detail on the testing sessions and measurements is provided below as well as an example of a training session:

- **Battlezone** – Participants will re-create a match situation by participating in a range of Battlezone scenarios on the centre wicket of a normal cricket ground, but will be surrounded by a net on the 30 m circle. This new training technique looks to provide realistic practice enabling the transfer of skills to the real game. An example a Battlezone is seen below.

- **Traditional Cricket Training** – Will include a regular net session (batting and bowling) as well as a range of fielding drills.

- **Cricket-specific Tests** – This will include batting and bowling skills tests (CA approved) and a throwing accuracy test to determine your current and progressive skill levels.

- **Fitness Tests** – Will include tests such as the Yo-Yo test, 40 m sprint and vertical jump to measure your different levels of aerobic, anaerobic and power fitness, respectively. Specifically the Yo-Yo test is similar to a ‘Beep Test in that it involves maximal intensity running efforts over a short distance however, participants are given a short active rest period between efforts.

- **Motion Analysis** - A Minimax Global Positioning System (GPS) monitor will be worn by each participant during the testing sessions. The GPS monitor provides information on the intensity and distance covered across the sessions.

- **Video Analysis** – Each training session will be recorded via a portable video camera and linked with the GPS data to accurately determine your movement patterns.

- **Heart Rate (HR)** – A Polar HR monitor will be worn by each participant during the testing session. The HR monitor provides information on the number of times your heart beats throughout a session.

- **Blood Lactate (BLa) –** A small amount of blood (≤5μl) will be drawn from each participant’s ear using a retractable lancet at specific times throughout each session. This blood sample will provide you with your blood lactate level using a portable blood lactate analyser. Blood samples will be taken a maximum of 8 times during each Battlezone session and 8 times during each Traditional training session.

- **Rating of Perceived Exertion (RPE)** – You will be asked to subjectively rate the intensity level of each testing session based on a scale of 1 – 10 (nothing at all – very, very hard).
- Core Temperature ($T_{\text{core}}$) – A VitalSense ingestible capsule (similar in size to a tablet) will wirelessly transmit a signal of your internal body temperature to an external data recorder throughout the session. Ingestion of the capsule will be required several (4-5) hours prior to the testing session.
- Skin Temperature ($T_{\text{skin}}$) – Several VitalSense dermal patches will be placed on specific anatomical landmarks (chest, upper arm, lower back, thigh and calf on the right hand side of the body) prior to testing to record peripheral (skin) temperature, with no interference in performance during the session.
- Hydration Status – Prior to each session your nude mass will be recorded. During each session you must only drink from assigned water bottles to closely monitor your fluid intake. Upon completion of the sessions a urine sample will need to be provided and again nude mass recorded. For nude mass to be recorded participants will be required to remove all clothing except for underwear in a closed room away from the public area, and step on a set of scales. Once measured participants are free to place clothing back on.

*Example of a Battlezone Training Session and Rules*

- **Rules:**
  - Maximum 2 bowlers rotating
  - Bowlers can bowl any length, any line
  - Bowlers aim is to dry up the runs
  - Fielder must throw to wicketkeeper or at bowler’s end stumps after ball is fielded
  - Hit-and-run (looking to replicate middle overs of limited-overs match, keep runs ticking over)
Batsmen aim to score only through the specified region (can be placed anywhere), of any ball they wish and counts for one run when completed.

- Balls not hit on the ground, or when batsmen loses their wicket counts for minus one run
- Normal cricket rules apply

**How much time will it take?**

There will be two testing sessions per week over a period of ten non-consecutive weeks spaced out across the regular cricket season. The duration of each session should last no longer than two hours. Once the training session has finished, you will not be required to remain at the complex.

**What are the risks and benefits of participating?**

During testing you will be required to perform maximal intensity exercise as a result of the cricket-specific movements which may cause some discomfort. You will be pre-screened to ensure that you do not have any existing medical conditions that may place you at risk of injury when undertaking this exercise. You will be referred to a general practitioner to obtain approval if an existing medical condition is present.

The GPS devices measure slightly less than 90 x 45 x 25mm, and weigh approximately 75g each. When worn in a performance undergarment, the GPS device is non-invasive to your regular movements. You may initially have a loose awareness of the GPS device, which will diminish following a familiarisation period. The GPS device will have no effect on your performance.

The ingestible capsule (approximately the size of a jelly bean) is made from biocompatible polycarbonate which cannot be broken down and is non-toxic, and is swallowed with liquid and easily travels the GI tract without affecting bodily functions. Upon completion of the testing sessions the capsule will simply pass out of the body as waste. The dermal temperature patches are applied directly onto the skin by a hypoallergenic adhesive. A very small amount of discomfort may occur when removing the patches. Your participation in this research will be beneficial to you as researchers will provide you with feedback about your movements and physiology whilst playing.

The activities performed during the study mirror those which occur during a typical cricket match. As such, you will be subject to those risks normally associated with cricket such as high-speed ball impacts or fatigue- and overuse-related injuries. To minimise these risks you will be required to bring your own protective gear (cricket kit) and wear what you would normally compete in (e.g. batting leg guards, batting gloves, helmet, wicketkeeping leg guards, correct
footwear etc.). If injuries do occur as a result of cricket-specific activities, first-aid will be provided by those in the research team to the best of their abilities.

**How will your privacy be protected?**

The confidentiality of this study is assured. Under no circumstances will any names appear on publications associated with this research. The individual results will be provided to you in verbal and written form with no one else being given the results unless you request it. Hard copies of results will be stored in a locked filing cabinet along with backed up data stored securely (password protected) in the filing cabinet. The researchers are the only personnel who have access to the data. Your confidentiality will be ensured by replacing your name with a numerical code. The data will be retained for a minimum of five (5) years, at the University of Newcastle. This is in accordance with the University of Newcastle Research Data and Materials Management Policy.

**How will the information collected be used?**

Data will be presented in scientific journals and in a thesis to be submitted for Mr William Vickery's doctoral studies. At the conclusion of the data collection, a summary will be presented to the participants, with no personal information included in these summaries. A written summary of the results will also be made available to the participants detailing the results and implications of the research. Each session will be videotaped for a more detailed analysis of cricket training activities. You will be able to view the tape at any time to review the recording and edit or erase your contribution.

**What do you need to do to participate?**

Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, contact the researcher.

If you would like to participate, please complete the attached pre-exercise health screening questionnaire and the consent form. This will be collected immediately.

If you are a suitable participant for this study, you will be contacted within three (3) days to confirm you inclusion in this study. If the pre-exercise health screen has identified any medical contraindications, you will be required to seek a medical clearance before being included in the study.
Further information

If you would like further information please contact William Vickery and/or Ben Dascombe for further information regarding the study.

William Vickery
- Phone: (02) 4932 3632
- Mobile: 0407 323 634
- Email: William.Vickery@uon.edu.au

Ben Dascombe
- Phone: (02) 4348 4150
- Mobile: 0417 712 381
- Email: Ben.Dascombe@newcastle.edu.au

Thank you for considering this invitation.

Dr Ben Dascombe  Mr William Vickery
Project Supervisor       PhD Student

Complaints about this research

This project has been approved by the University’s Human Research Ethics Committee, Approval No. H-2010-1288. Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Office, The Chancellery, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone (02) 49216333, email Human-Ethics@newcastle.edu.au.
I agree to participate in the above research project and give my consent freely.

I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.

I understand that the purpose of this study is to examine acute physiological and perceptual responses and time-motion characteristics associated with various Battlezone formats and compare these to traditional cricket training methods.

I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing.

I consent to:

- Undergo pre-screening procedures that involve a health questionnaire and the collection of personal details
- Complete a range of Battlezone and traditional cricket training activities across a regular cricket season
- Complete a number of cricket-specific skills tests
- Undergo basic anthropometric measurements including height, nude weight and skinfolds
• Wear Minimaxx GPS devices whilst completing Battlezone and normal cricket training activities
• Wear a Polar heart rate monitor whilst completing Battlezone and normal cricket training activities
• Allow small blood samples to be taken from the earlobe
• Ingesting a small capsule to measure internal body temperature prior to each testing session
• Wear patches on your skin to measure external body temperature whilst completing Battlezone and normal cricket training activities
• Provide urine samples
• Provide ratings of perceived exertion following training or testing sessions
• Allowing video recording of sessions to be used in post-training analysis by the researchers
• Allowing data collected and video recordings showing participants image to be used in reports and presentations

I understand that participation in the research will expose participants to those risks associated with cricket-specific movements.

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name: ____________________________________________

Signature: ____________________________________________

Date: ____________________________________________

Contact Details: ___________________________________

Ph: ____________________________________________

Email: ____________________________________________
Appendix D

*Human Research Ethics Approval (Studies 2-5)*
HUMAN RESEARCH ETHICS COMMITTEE

Notification of Expedited Approval

To Chief Investigator or Project Supervisor: Doctor Benjamin Dascombe
Cc Co-investigators / Research Students: Dr Rob Duffield
                                                Mr William Vickery
Re Protocol: Physiological and perceptual responses and
            movement characteristics of cricket players during
            Battle Zone
Date: 16-Dec-2010
Reference No: H-2010-1288
Date of Initial Approval: 16-Dec-2010

Thank you for your Response to Conditional Approval submission to the Human Research Ethics Committee (HREC) seeking approval in relation to the above protocol.

Your submission was considered under Expedited review by the Chair/Deputy Chair.

I am pleased to advise that the decision on your submission is Approved effective 16-Dec-2010.

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research, 2007, and the requirements within this University relating to human research.

Approval will remain valid subject to the submission, and satisfactory assessment, of annual progress reports. If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.

The full Committee will be asked to ratify this decision at its next scheduled meeting. A formal Certificate of Approval will be available upon request. Your approval number is H-2010-1288.

If the research requires the use of an Information Statement, ensure this number is inserted at the relevant point in the Complaints paragraph prior to distribution to potential participants. You may then proceed with the research.

Conditions of Approval

This approval has been granted subject to you complying with the requirements for Monitoring of Progress, Reporting of Adverse Events, and Variations to the Approved Protocol as detailed below.

PLEASE NOTE:
In the case where the HREC has "noted" the approval of an External HREC, progress reports and reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, or a Renewal of approval, you will apply to the External HREC for approval in the first instance and then Register that approval with the University’s HREC.

https://rms.newcastle.edu.au/administration/ShowPDF.asp?ID=977C7D4C778018F1ED04400144F3E5AAB
• Monitoring of Progress

Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. A progress report is required on an annual basis. Continuation of your HREC approval for this project is conditional upon receipt, and satisfactory assessment, of annual progress reports. You will be advised when a report is due.

• Reporting of Adverse Events

1. It is the responsibility of the person first named on this Approval Advice to report adverse events.
2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
3. Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Approval Advice to the (HREC) by way of the Adverse Event Report form within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
4. Serious adverse events are defined as:
   - Causing death, life threatening or serious disability.
   - Causing or prolonging hospitalisation.
   - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
   - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
   - Any other event which might affect the continued ethical acceptability of the project.
5. Reports of adverse events must include:
   - Participant's study identification number;
   - date of birth;
   - date of entry into the study;
   - treatment arm (if applicable);
   - date of event;
   - details of event;
   - the investigator's opinion as to whether the event is related to the research procedures; and
   - action taken in response to the event.
6. Adverse events which do not fall within the definition of serious or unexpected, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.

• Variations to approved protocol

If you wish to change, or deviate from, the approved protocol, you will need to submit an Application for Variation to Approved Human Research. Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. Variations must be approved by the (HREC) before they are implemented except when registering an approval of a variation from an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

Linkage of ethics approval to a new Grant

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.
Best wishes for a successful project.

Professor Alison Ferguson  
Chair, Human Research Ethics Committee

For communications and enquiries:  
Human Research Ethics Administration

Research Services  
Research Office  
The University of Newcastle  
Callaghan NSW 2308  
T +61 2 492 18999  
F +61 2 492 17164  
Human-Ethics@newcastle.edu.au

Linked University of Newcastle administered funding:

<table>
<thead>
<tr>
<th>Funding body</th>
<th>Funding project title</th>
<th>First named investigator</th>
<th>Grant Ref</th>
</tr>
</thead>
</table>
Appendix E

Pre Exercise Health Screening Questionnaire
<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Have you ever had a heart attack, coronary revascularisation surgery or stroke?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>2</td>
<td>Has your doctor ever told you that you have heart trouble or vascular disease?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>3</td>
<td>Has your doctor ever told you that you have a heart murmur?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>4</td>
<td>Do you suffer from pains in your chest, especially with exercise?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>5</td>
<td>Do you get pains in your calves, buttocks or at the back of your legs during exercise which are not due to soreness or stiffness?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>6</td>
<td>Do you ever feel faint or have spells of severe dizziness, particularly with exercise?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>7</td>
<td>Do you experience swelling or accumulation of fluid about the ankles?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>8</td>
<td>Do you ever get the feeling that your heart is suddenly beating faster, racing or skipping beats, either at rest or during exercise?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>9</td>
<td>Do you have chronic obstructive pulmonary disease, interstitial lung disease, or cystic fibrosis?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>10</td>
<td>Have you ever had an attack of shortness of breath that developed when you were not doing anything strenuous, at any time in the last 12 months?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>11</td>
<td>Have you ever had an attack of shortness of breath that developed after you stopped exercising, at any time in the last 12 months?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>12</td>
<td>Have you ever been woken at night by an attack of shortness of breath, at any time in the last 12 months?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>13</td>
<td>Do you have diabetes (Type I/Type II)?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>If so do you have trouble controlling your diabetes?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>14</td>
<td>Do you have any ulcerated wounds or cuts on your feet that do not seem to heal?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>15</td>
<td>Do you have any liver, kidney or thyroid disorders?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>16</td>
<td>Do you experience unusual fatigue or shortness of breath with usual activities?</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>
Is there any other physical reason or medical condition that could prevent you from undertaking testing and exercise that you are concerned about? Provide details below.

____________________________________________________________________________
____________________________________________________________________________
____________________________________________________________________________
____________________________________________________________________________

The responses of the questionnaire will be assessed and you will be notified if you are able to begin the study, or if you require a medical clearance from a general practitioner before commencing.

If you have any questions regarding the questionnaire, please do not hesitate to contact me at the details listed on the previous page.

Risk Factors:

Signs and Symptoms:

Health Screening Status:

Action:

____________________________________________________________________________

William Vickery (BSc Hons)