Elite cricket match and training demands and performance enhancement in hot / humid environments

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STATEMENT OF ORIGINALITY

This thesis describes original research conducted by the author at Cricket Australia's Centre of Excellence and the Australian Institute of Sport while enrolled in the School of Sport Science, Exercise and Health at the University of Western Australia from February 2007 to November 2010. The work in this thesis has been completed by the candidate except where described in the thesis itself. This work has not previously been submitted for a degree or diploma in any University. To the best of my knowledge and belief, the thesis contains no material previously published by another person except where due reference is made explicitly.

A number of individuals have contributed substantially to the research presented in this thesis. Their contributions follow:

- Prof. Brian Dawson Research design, data interpretation and manuscript review
- Prof. David Pyne Research design, data interpretation and manuscript review
- Dr. Marc Portus Research design, data interpretation and manuscript review
- Mr. Aaron Kellett Data collection
- Mr. Justin Cordy Manuscript review (Study 1 only)
- Mr. Stuart Karppinen Manuscript review (Study 4 only)
- Mr. Matthew Cramer Data collection (Study 9 only)

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EXECUTIVE SUMMARY

Cricket is one of the world's most popular field sports particularly in Commonwealth nations. Despite this popularity there are few published studies on fitness requirements of international cricket. The variable playing duration of three (Twenty20) to 30 hours (five day Test Match) in cricket combined with a large playing field has made it difficult to conduct time-motion studies by traditional means (pen and paper or video recording). Global Positioning System (GPS) athlete monitoring technology now provides a more time efficient and practical method to quantify movement patterns in cricket, provided this technology has adequate validity and reliability.

Determination of the validity and reliability of GPS monitoring was required to assess the utility of this approach in quantifying the physical demands of cricket. We compared the validity and reliability of three commercially-available GPS models in estimating cricket-specific movements against criterion measures (400-m athletic track, electronic timing) of distance and velocity. Two models operated with a 5-Hz GPS signal (MinimaxX and SPI-Pro), whereas the third model operated with a 1-Hz GPS signal (SPI-10). For walking to striding the mean validity and reliability of estimating distances from 600–8800 m by the GPS units ranged from ~0.3 to 5.2% and ~0.2 to 4.0% respectively. In contrast, the mean validity and reliability for estimating sprint distances over 20-40 m including the cricket specific run-of-three, was substantially worse and ranged from ~1.6 to 34% and ~1.6 to 40% respectively. The relatively poor reliability and validity of measuring short sprints with GPS technology means that support staff should interpret small changes and differences in

movement patterns with caution. An improvement in GPS hardware specifications, firmware and software is required before GPS data on short sprints can be interpreted with confidence.

The physiological demands of cricketers vary considerably between batsmen, fast bowlers, spin bowlers, wicketkeepers and fielders. A longitudinal two-year study of academy cricketers was undertaken to quantify movement patterns (using GPS athlete tracking technology) for these positions in elite Twenty20, 50-over and multi-day or first class matches, and magnitude of differences and variability between game formats. In Twenty20 competition, cricketers in the field (excluding wicketkeepers) typically covered between 8.1 - 8.5 km during an 80 min innings, with 0.2 – 0.7 km of this distance spent at sprinting velocities. Although a Twenty20 innings is typically only 38% of the time taken for a One Day innings, fast bowlers covered 53% of the total distance and 63% of the sprinting distance for international One Day matches. Faster bowlers in Twenty20 cricket were physically the most active per unit of game time. The number of sprints was the most variable time-motion measure. Across positions and game formats the coefficient of variation (CV) for the number of sprints ranged from 25 to 200%, in contrast the CV for total distance only varied by between 9 – 27%. The volume and duration of sprinting that a player in a particular position undertook appears to depend largely on the game circumstances, whereas the distances covered walking and jogging are more consistent from game to game.

During an intensive 14-week residential training camp fourteen elite cricketers were monitored using GPS units, heart rate monitoring and blood lactate measurements to quantify the pattern of physiological demands of contemporary cricket training. Conditioning drills matched or exceeded (by up to 10 beats·min^{-1}; ~5 %) peak game heart rates, whereas skill and

simulation drills replicated mean game heart rates for some, but not all positions. Conditioning drills were twice as long in duration as skill drills and twice as intense as both the skill and game simulation drills. These data challenge practitioners to re-design and/or modify traditional training drills to ensure that sufficient training intensities are prescribed.

Elite cricketers are often required to perform in hot and humid conditions, with little time for heat adaptation. Two controlled studies in senior male cricket players were undertaken to evaluate the physiological and performance effects of a short 4 day high intensity heat acclimation protocol typically used at the elite level. Physiological variables indicative of heat acclimation (i.e. increased sweat rate, diluted sweat composition, lower exercising heart rate, lower core temperature and perceived comfort levels) were monitored to quantify the extent of acclimation using this approach. The magnitude of within-group acclimation changes was also compared to those achieved naturally from controlled training in a mild and hot (acclimatisation) environment. The acclimatisation group (n=9) had substantial moderate to large decreases (23–43%) in sweat electrolyte concentrations, while the acclimation group (n=5) only had a trivial to moderate 11-17% reductions in sweat electrolyte concentrations. Between groups there was a 9–34% greater reduction in sweat electrolyte concentrations for the acclimatization group. The magnitudes of all other indicators of heat adaptation were similar between these groups. While four 30-45 min high intensity cycle sessions in hot/humid conditions elicited partial heat acclimation, a more intensive and/or extensive (and exercise-specific) acclimation protocol is recommended to elicit full heat acclimation for cricketers preparing for adverse environmental conditions.

In conclusion, time motion match data has shown that fast bowlers have the greatest physical demands of any position. While for all positions the physical demands of the shorter formats of cricket (Twenty20 and One Day) are more intensive per unit of time, multi-day cricket has a greater overall physical load. GPS units have adequate precision for estimating longer distances but need further improvement to confidently estimate the short sprinting movements of cricketers. Conditioning coaches can utilise GPS-derived time-motion data for training prescription and recovery practices. Although a short 4 day heat acclimation and acclimatization program provides some thermoregulatory benefits, a longer program is needed for full acclimation to challenging environmental conditions.

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Chapter 1

Introduction

1.0 Introduction

Written legal evidence from Guilford, Surrey suggests cricket has been played as far back as 1550. Despite being one of the world's oldest sports, there has been minimal scientific enquiry into the physical and tactical requirements of cricket. Some investigators (Christie et al., 2008; Duffield et al., 2009) have conducted simulation studies to replicate game demands. However, only a small number of observational studies investigating the fitness requirements of cricket have actually measured what players do within competition (Gore et al., 1993; Brearley and Montgomery, 2002; Brearley, 2003). Unfortunately, while partially quantifying the demands of cricket, the measurements made in these studies were not taken from elite competitors. Tactical decisions and strategies, for example how and when different player positional types are employed in the game, have not received any attention in the scientific literature. Coaches need more specific guidelines and recommendations based on scientific evidence to enhance the training and game performance of cricketers.

Time-motion analysis is employed in a number of sports to provide a quantitative description of competition demands. Only two studies of cricket have been undertaken utilising video-based time motion analysis (Duffield and Drinkwater, 2008; Rudkin and O'Donoghue, 2008). However, these studies were limited to only one position (batting, or the cover-point fielder), and relatively few observations. By far, the greatest limitation of the time-motion (or notational analysis) studies is the time-consuming nature of the process itself. The long post-processing time combined with the ability to analyse only a single player at a time, makes this method somewhat

impractical for deriving and then disseminating any meaningful information to coaching staff within a reasonably short time-frame.

Game analysis techniques in high-level cricket should be capable of measuring multiple players simultaneously, have a rapid post-processing time, and provide valid and reliable information to coaching staff. The recent application of Global Positioning System (GPS) technology to athlete tracking shows some promise in achieving these objectives (Edgecomb and Norton, 2006; Randers et al., 2010). Given the relative infancy of the new technology, the validity and reliability of this method has not been reported for cricket, which is played for an extended duration (multiple hours) and includes a large proportion of walking. It is readily apparent that a comprehensive validity and reliability study of GPS monitoring in cricket is needed. Cricket is unique in comparison to most sports in the very high proportion of time spent in actual competition versus training. Unlike other outdoor-based sports (e.g. distance running, triathlon, football, field hockey), that may track training and competition volume in terms of distance travelled, analysis of movements in cricket becomes complicated as players are involved in the game for different durations and have distinct roles within the game itself. Game tactics often dictate when and how much involvement a particular player has in an innings or a full game. Understanding the workload that a cricket player commonly undertakes is rudimentary at best. The ability with GPS technology to (within minutes) provide the total distance and distance covered in various movement patterns should enable conditioning staff to better individualise and modify subsequent training / recovery sessions. Accumulation of longitudinal game movement data will permit development of position, game and level-specific reference values.

Unlike other sports, such as Australian Football (Dawson et al., 2004) and Association Football (Bangsbo et al., 2006), there is a total void of published scientific information on the physical demands of cricket training practices. There is a clear need to describe, quantify and compare the training practices commonly used in contemporary cricket to the physical demands of the game. The physiological analysis of a full range of training activities, (using GPS technology, heart rate monitoring and blood lactate measurements) should be useful in monitoring the effects of an intensive winter training program for cricketers. Analysis of training data over this period is needed to compare the physical demands between various training activities and actual competition play.

As a global game, cricket at the elite level is often played in geographical regions where there are challenging environmental conditions. Given congested international schedules a touring side is often required to play matches before the players have time to fully acclimate to the ambient environmental conditions. Athletes from temperate climates, require up to 10-14 days of acclimatisation to attenuate the negative effects of heat and humidity (Terrados, 1995). However, any cricket specific training intervention must be of a sufficiently short duration to enable its use during the brief duration pre-departure training camp or between arrival and the first game of a tour. The other requirement of a training intervention is the need to carefully programme the total training load taking account of all training practices. Any original thermoregulation investigation of preparation methods for cricketers should be based on known information (from other sports) adapted to the constraints of what is practically possible to implement with elite cricketers.

1.1 Statement of the Problem

Understanding the physical demands of the various game formats in cricket should lead to enhanced physical preparation of players. Analysis of the physiological demands of games and contemporary training drills can be used to develop or modify the prescription of training drills to ensure training matches or exceeds game demands. An awareness of both physical and game tactics in cricket will assist the interpretation of positional game demands. A greater understanding of the physical game demands for various playing positions during different formats of cricket should allow better individualisation of fitness training and recovery. Comparing the magnitude and timecourse of different heat adaptation training regimes is needed to design more effective training programs for promoting rapid adaptation to hot /humid environments.

1.2 Aims

- Determine the differences in tactics between winning and losing teams in both 50-over and Twenty20 cricket competitions.
- Quantify the reliability and validity of GPS technology for measuring cricket-specific distances and movement speeds.
- Quantify the physiological demands experienced during the different game formats and levels of competition for the various player positions.
- Quantify the physiological demands of contemporary training drills and how these compare to the physiological game demands of elite cricket.

- Compare the effects of a cricket-specific short duration heat acclimatisation with heat acclimation using classical indicators of heat adaptation.

1.3 Organisation and Structure of the Thesis

This thesis is organised as a series of chapters, based primarily on manuscripts either published or accepted for publication in peer-reviewed scientific journals. Following this chapter (Introduction) the Review of Literature (Chapter 2) examines the physical attributes of cricketers, time-motion studies of game demands and various simulations detailing the physiological responses and movement patterns of cricketers. Chapters 3 to 7 include ten original investigations that address:

- the key indicators of successful performance in One Day and Twenty/20 forms of the game (Studies 1 and 2)
- the reliability and validity of using GPS units for time-motion studies in cricket (Study 3)
- time-motion studies utilising GPS units for describing the physical demands of various aspects of cricket (Studies 4 to 7)
- the physiological demands of training activities and how these compare to game demands (Study 8)
- strategies for improving heat adaptation for cricketers required to perform in challenging environmental conditions (Study 9 and 10)

Finally, the Discussion and Conclusion sections (Chapters 8 and 9) integrate the findings of this thesis and present conclusions, implications and directions for future research. The thesis is also supported by additional pieces of work presented in the appendices. These appendices include conference oral and poster presentations that

describe differences in GPS technology of different frequencies, GPS-defined seasonal fast bowler workloads, and early versus late season Twenty20 game demands.

1.4 Significance of the Study

The findings of this research are directly applicable to contemporary cricket players. The outcomes should assist coaches to formulate game tactics, and provide conditioning coaches with the evidential basis to enhance the physical preparation of players using format- and position- specific training programmes. This research challenges current training methods and provides a template to match training and game demands. Finally, this research should help trainers and sport scientists in their design of preparation strategies for cricketers touring countries with hot and humid environments.

Chapter 2

Review of Literature

2.0 Abstract

This review presents an analysis of scientific research on the fitness requirements for cricket and associated physical preparation strategies used for different formats of the game. Time-motion studies have not yet defined the game-specific requirements of various cricketing positions, formats and performance levels. Anthropometric studies have partly defined the physical characteristics of elite cricketers, while other studies have identified some traits associated with skilled performance. Simulation studies offer promise in measuring physiological responses of cricketers to replicate match situations. A limited number of studies have investigated the physiological demands during actual match play, however there is still a lack of data for all cricket positions. Future research should address the effectiveness of actual conditioning practices and specific training drills for cricketers. Only a few studies have investigated the physiological responses of cricket players to hot/humid environmental conditions; specific heat acclimatization for pace bowlers via a one-day tournament conferred progressive cardiovascular adaptations however it was also shown to have negative consequences (decline in bowling velocity and increase in ratings of muscle soreness) due to inadequate recovery (Brearley, 2003). With the amount of cricket played in environmentally harsh conditions there is a clear need for further work in this area.

2.1 Introduction

Historically, scientific research into the sport of cricket has been sparse (Noakes and Durandt, 2000). Only, within the last decade has there been an increased amount of scientific activity and enquiry in the sport. Highlighted by increased numbers of cricket research publications appearing in sport science journals, the increased level of

academic enquiry may be partly attributed to the influence of the first three World Congresses of science and medicine in cricket (Lilleshall, England 1999; Cape Town, South Africa, 2003; and Barbados, 2007). A number of reviews of batting (Stretch et al., 2000), fast bowling (Bartlett et al., 1996; Elliott et al., 1996; Elliott, 2000), prevention of cricket injuries (Finch et al., 1999; Stretch, 2007), physiological requirements of cricket (Noakes and Durandt, 2000) and the game in general (Bartlett, 2003) have been published. Yet, despite this body of work, 'the fitness demands of the game are still poorly understood' (Bartlett, 2006).

Most research into the game has addressed the high prevalence of injuries to cricket fast bowlers, with a particular emphasis on fast bowling technique and the mechanism(s) of lower back injuries (Elliott and Foster, 1984; Foster et al., 1989; Burnett et al., 1995; Portus et al., 2000; Wallis et al., 2002; Portus et al., 2004; Ranson et al., 2009). While not discounting the importance of technique and injury risk especially in enhancing the health, performance and playing longevity of cricketers, the present review will focus on fitness and performance aspects of cricket. This review will address the physical demands of cricket, fitness characteristics and morphology of cricketers, training and/or conditioning practices and thermoregulation of cricketers.

2.2 Physical demands of Cricket

Several methods, including mathematical estimations, time-motion studies and direct physiological measurements have been employed to study the physical demands of cricket. Using a mathematical approach, Fletcher (1955) estimated a 650 $kJ.h^{-1}$ average hourly energy expenditure for cricketers playing a five test tour (5 games =

25 days). These calculations probably underestimated the actual energy requirement during play because periods when a Test fielder watched the game (from the pavilion, during the batting innings) were also included. The variables used by Fletcher to derive his estimations included; the observed mean runs scored, overs bowled and balls fielded; the duration of batting, bowling, fielding and sitting in the pavilion; and the estimated distances covered in each activity (utilising the known pitch length).

The energy requirement of one-day cricket batsmen (2536 $kJ.h^{-1}$) has also been measured during a simulated seven-over work bout by Christie et al., (2008). This study utilised a portable on-line metabolic system (Cosmed K4b2) to obtain heart rate, ventilation, oxygen uptake and carbon dioxide production data. These studies provide an indirect estimate of expected energy expenditure values for batsmen and fielders. However no study has measured the actual energy requirements of cricketers during matches. Actual energy expenditure will likely vary depending on the player's role or position and format of cricket being played.

In the last few years both video (Duffield and Drinkwater, 2008; Rudkin and O'Donoghue, 2008) and Global Positioning System (GPS) methods (Petersen et al., 2009[a,b]; Petersen et al., 2010) have been employed to perform time-motion studies of actual cricket match play. These methods have begun to define positional distances covered and the movement speeds undertaken during different formats of match play. Table 1 provides a summary of published time motion measures and demonstrates that fast bowlers cover the greatest total distance and greatest distance at sprinting intensities. In contrast, wicketkeepers seldom perform at sprinting intensities. With the exception of fast bowlers, over 90% of the distance covered during multi-day format is covered at walking and jogging intensities. As evidenced, by the total

distance, sprint distance covered and number of sprints the shorter game formats (Twenty20 and One Day) are more intensive per unit time.

The physiological requirements of cricket have also been investigated using a range of measures (e.g. core temperature, heart rate, sweat rate) during actual match play (Gore et al., 1993; Brearley and Montgomery, 2002; Brearley, 2003; Soo and Naughton, 2007) or during simulated components of match play (Burnett et al., 1995; Stretch and Lambert, 1999; Christie et al., 2008; Duffield et al., 2009). Table 2 provides a summary of published physiological demands. In general, cricketers have low to moderate sweat rates ranging from 0.5 to 1.7 $L.h^{-1}$. Mean and peak game heart rates range between 116–170 and 150-180 $beats{\cdot}min^{-1}$ respectively. Only a few studies have reported blood lactate measures for cricketers; batsmen range between 2 – 3 $mmol.L^{-1}$ and fast bowlers are reported to range between 3 - 5 $mmol.L^{-1}$. There has also been limited reporting of core temperature measures, however it seems that batsmen will have peak core temperature readings in the mid 38°C range, whereas fast bowlers may reach values just above 39°C. It appears that the heart rate values of batsmen in particular are substantially lower for the multi-day cricket format in comparison to both Twenty20 and One Day formats. It is useful to summarise research into the physical demands of cricket by the various roles within the game: batsmen, bowlers (slow and fast), fielders, and wicketkeepers.

Table 1. Hourly values (mean ± sd) of published time motion variables for different cricket positions

Source and observations (#)	Level	Format	Total distance (m)	Sprint distance (m)	Sprints (#)	High intensity efforts (#)	% distance from walking and jogging
Batsmen							
Petersen et al. (2009) n=6	State	Twenty20	4866 ± 900	322 ± 166	24 ± 10	77 ± 34	83
Petersen et al. (2009) n=26	Academy	Twenty20	2429 ± 516	175 ± 97	15 ± 9	45 ± 16	81
Petersen et al. (2009) n=36	Academy	One day	2476 ± 618	149 ± 94	13 ± 9	39 ± 16	84
Duffield & Drinkwater, (2008) n=5	International	One day					94*
Petersen et al. (2009) n=9	Academy	Multi-day	2064 ± 550	86 ± 28	8 ± 3	28 ± 6	87
Duffield & Drinkwater, (2008) n=13	International	Test					96*
Fast bowlers							
Petersen et al. (2009) n=4	State	Twenty20	6367 ± 1120	542 ± 126	32 ± 6	122 ± 33	76
Petersen et al. (2009) n=18	Academy	Twenty20	4172 ± 671	406 ± 230	23 ± 10	61 ± 25	80
Petersen et al. (2009) n=24	Academy	One day	3833 ± 594	316 ± 121	18 ± 5	54 ± 14	82
Petersen et al. (2009) n=12	International	One day	4544 ± 729	326 ± 70	19 ± 3	55 ± 9	84
Petersen et al. (2009) n=10	Academy	Multi-day	3773 ± 669	230 ± 149	17 ± 11	56 ± 29	83
Fielders							
Petersen et al. (2009) n=14	State	Twenty20	6106 ± 981	416 ± 265	23 ± 13	97 ± 43	79
Petersen et al. (2009) n=26	Academy	Twenty20	3447 ± 717	129 ± 91	8 ± 5	42 ± 20	86
Petersen et al. (2009) n=52	Academy	One day	3081 ± 550	81 ± 51	5 ± 3	27 ± 11	89
Petersen et al. (2009) n=20	Academy	Multi-day	2477 ± 506	52 ± 33	3 ± 2	19 ± 8	91
Rudkin & O'Donoghue, (2007) n=27	First-class	Multi-day	2580				92
Spin bowlers							
Petersen et al. (2009) n=3	State	Twenty20	6430 ± 1176	115 ± 108	7 ± 6	42 ± 26	93
Petersen et al. (2009) n=10	Academy	Twenty20	3293 ± 447	81 ± 55	5 ± 4	25 ± 12	91
Petersen et al. (2009) n=8	Academy	One day	3130 ± 293	58 ± 37	4 ± 1	29 ± 10	91
Wicketkeepers							
Petersen et al. (2009) n=3	State	Twenty20	4825 ± 570	46 ± 33	4 ± 2	37 ± 9	93
Petersen et al. (2009) n=3	Academy	Twenty20	2483 ± 482	59 ± 23	5 ± 2	30 ± 18	86
Petersen et al. (2009) n=4	Academy	Multi-day	2766 ± 347	23 ± 30	2 ± 4	12 ± 6	96

* % time spent walking and jogging, not distance.

Note: Sprinting is defined as locomotion movement above $5 m \cdot s^{-1}$, and a high intensity effort is defined as movement greater than $3.5 m \cdot s^{-1}$ (jogging) for more than one second.

Table 2. Physiological demands of batting, fast bowling, fielding, spin bowling and wicketkeeping.

Source and observations (#)	Level	Format	Mean Hr (bpm)	Peak Hr (bpm)	Sweat rate ($L.h^{-1}$)	Peak Core temp (◦C)	Peak Lactate ($m \cdot mol \cdot L^{-1}$)
Batsmen							
Christie et al. (2008) ¤ (n=10)	Club	One Day	145 ± 11	155 ± 19	-	-	-
Petersen et al. (2009) (n=16)	Academy	T20	149 ± 17	181 ± 14	-	-	-
Petersen et al. (2009) (n=5)	Academy	One Day	144 ± 13	180 ± 13	-	-	2.4 ± 0.4
Gore et al. (1993) (n=6) – Warm¤	Club	Multi-day	129 ± 2	-	0.60 ± 0.05	38.6 ± 0.03	-
Gore et al. (1993) (n=6) – Cool¤	Club	Multi-day	110 ± 2	-	0.47 ± 0.04	38.3 ± 0.03	-
Brearley & Montgomery (2002) (n=5)	Academy	One Day	167 ± 4	174	1.00 ± 0.1	38.5 ± 0.2	3.1 ± 0.8
Fast bowlers							
Duffield et al. (2009)¤ (n=6)	State	First class	162 ± 12★	-	-	38.8 ± 0.8	5.0 ± 1.5
Petersen et al. (2009) (n=10)	Academy	T20	133 ± 12	181 ± 10	-	-	-
Gore et al. (1993) (n=3) – Hot	Club	Multi-day	-	-	1.67 ± 0.08	-	-
Gore et al. (1993) (n=5) – Warm¤	Club	Multi-day	116 ± 2	-	0.69 ± 0.05	38.0 ± 0.03	-
Gore et al. (1993) (n=7) – Cool¤	Club	Multi-day	131 ± 2	-	0.71 ± 0.04	38.3 ± 0.03	-
Brearley & Montgomery (2002) (n=7)	Academy	One Day	-	174	0.81 ± 0.2	38.7	3.3 ± 0.8
Brearley & Montgomery (2003) (n=4)	Academy	One Day	-	-	0.72	39.2 ± 0.3	3.5 ± 0.6
Burnett et al. (1995) (n=9) ¤	Academy	One Day	171 ± 4★	176 ± 12	-	-	5.1 ± 2.5
Stretch and Lambert, (1999) ¤	Junior	-	158 ± 10	-	-	-	-
Stretch and Lambert, (1999) ¤	Senior	-	158 ± 8	-	-	-	-
Devlin et al. (2001) ¤	Club	-	154 ± 14	-	-	-	-
Fielders							
Petersen et al. (2009) (n=7)	Academy	T20	115 ± 20	159 ± 14	-	-	-
Petersen et al. (2009) (n=5)	Academy	One Day	109 ± 8	166 ± 5	-	-	-
Spin bowlers							
Petersen et al. (2009) (n=3)	Academy	T20	135 ± 6	176 ± 10	-	-	-
Wicketkeepers							
Petersen et al. (2009) (n=3)	Academy	T20	135 ± 19	165 ± 13	-	-	-
Brearley & Montgomery (2002) (n=1)	Academy	One Day				37.6	

★ Post over heart rate, ¤ Simulation study. Cool, warm and hot conditions had wet bulb globe temperature indices of 22.1, 24.5 and 27.1 respectively.

Batting

In batting, technical skills are the key to successful performance. Predictably, research has concentrated on these aspects of batting including visual performance and reaction times (Campbell et al., 1987; McLeod, 1987; Land and McLeod, 2000; Mann et al, 2007), anticipatory or advanced cue recognition (Abernethy and Russell, 1984; Deary and Mitchell, 1989; Penrose and Roach, 1995; Renshaw and Fairweather, 2000; Muller and Abernethy, 2006; Weissensteiner et al., 2008), hitting technique (Gibson and Adams, 1989; Busch and James, 2008), and moods and anxiety (Thelwell and Maynard, 1998; Totterdell, 1999; Totterdell and Leach, 2001). While receiving little attention, the physical demands of batting are also worthy of attention. Batsmen with greater upper body strength (bench press) have been shown to hit the ball further (Taliep et al., 2010), but did not have a greater overall batting performance (strike rate or average). Batsmen are often required to bat for long periods of time and relationships between fitness and the development of fatigue will almost certainly impact on performance.

A video-based study of century scoring international batsmen in ODI (n=5) and Tests (n=13) revealed that One Day centuries took 136 ± 21 min with 102 ± 18 balls (mean ± SD), compared with Test centuries that took 213 ± 32 min (57% longer), with 160 ± 23 balls (57% more deliveries) (Duffield and Drinkwater, 2008). This study qualitatively described movement patterns, but could only quantify the time spent in different movement patterns and not the actual distances. Nonetheless, sprinting in Test and One Day centuries accounted for 66 ± 30 s and 54 ± 30 s respectively, with 94 and 96 % of total time spent in walking and jogging intensities, for ODI and Test batsmen respectively. Batsmen scoring an ODI century face considerably less deliveries and bat for a shorter duration than their Test counterparts. However given a

higher amount of sprinting ODI batsmen could be executing their skills under a relatively higher level of physical exertion.

Utilising time-motion data a pilot study simulated high intensity one day batting in temperate conditions (Christie et al., 2008). Ten male university-level batsmen (wearing full protective equipment), performed four sprints per over (six balls) for a seven over period while physiological variables were monitored. The work period elicited a $\dot{V}0_2$ in the range from 20-30 ml.kg.min^{-1}, an estimated energy expenditure of 2536 kJ.h^{-1} and a respiratory exchange ratio (RER) above 1.00 from the second over onwards. The high RER value reflected the heavy anaerobic work of the single runs (17.68 m sprints) performed, and the moderate $\dot{V}0_2$ required indicated that even in a (simulated) high scoring game, there is adequate recovery time from a cardiovascular perspective. However simulation studies may underestimate the heart rate response as some external factors that influence heart rate (e.g. crowd noise, performance anxiety) are hard to replicate.

The mean and peak heart rates of cricket batsmen during match play range between 144–167 and 174–181 beats·min^{-1} (Table 2). However the simulation studies of Gore et al. (1993) and Christie et al. (2008) had lower mean and peak heart rates than those reported in the actual match studies. Future simulation studies should look to replicate the actual movement patterns of match play, which should induce a sweat rate while batting of between 0.6–1.0 L.h^{-1} and peak lactate measures of 2.4–3.1 mmol.L^{-1}. The game format, competitive level and the environmental conditions may affect these values. These data could also be utilised by coaches to ensure, when required, that structured training sessions exceed game demands to elicit an overload to stimulate adaptation.

Fast bowling

Fast bowlers have been classified as routinely delivering a ball at a release velocity between 128–144 $km \cdot h^{-1}$, whereas medium paced bowlers release the ball between 96-128 $km \cdot h^{-1}$ (Justham et al., 2006). A highly respected international cricket coach contends that 'Bowling fast is one of the most demanding activities in world sport: to reach the pinnacle of the game, and to prosper there, modern fast bowlers must be among the most athletic of humans. The rationale of having superior fitness for cricket is two-fold; it enhances the ability of playing at one's best and reduces the risk of serious injury' (Woolmer et al., 2008). Interestingly, studies have yet to adequately address the effectiveness of contemporary fitness programs in cricket and whether they have a substantial effect on cricket playing ability.

Studies have investigated the physiological demands of fast bowling by using simulations of either single 6, 8 or 12-over bowling spells (Burnett et al., 1995; Stretch and Lambert, 1999; Portus et al., 2000), or repeated (2x) 6-over bowling spells separated by either 45 or 60 min (Devlin et al., 2001; Duffield et al., 2009). While bowling technique does not change markedly during a 12 over spell, heart rate will range between 80-85% of maximal heart rate with blood lactate levels of 4.4 – 5.1 $mmol.L^{-1}$ (Burnett et al., 1995). No substantial changes in heart rate, lactate or core temperature and only small differences in bowling speed or accuracy were evident between two repeated six over bowling spells separated by 45 min (Duffield et al., 2009). In contrast, two six-over spells separated by 60 min showed that bowlers with a moderate (2.8% of body mass) level of exercise-induced dehydration impaired the accuracy but not maximal velocity of their bowling (Devlin et al., 2001). The major difference between these two studies was the exercise intensity performed between bowling spells -a 45min walk compared to a shuttle run in heated 28ºC

conditions. It appears that skilled bowling performance of the second spell is related to both the duration and the intervening exercise intensity between spells.

During the fast bowler's delivery stride laboratory-based studies have reported front and back foot peak braking forces between 1.4 – 2.5 and 1.0 – 1.1 times bodyweight respectively; peak vertical forces ranged between 4.1 – 9.0 (front foot) and 2.0 – 2.9 back foot) times bodyweight (Hurrion et al., 2000). Comparing middle distance runners measured at a similar approach speed (5.0 $m.s^{-1}$) the loading rates encountered in cricket bowling are relatively higher (298 versus 113 $BW.s^{-1}$) (Hurrion et al., 2000). Technical limitations have meant that it has not been possible to obtain breaking or vertical forces in actual match play. Possibly, these forces may differ especially later in games when the bowlers' foot marks dictate that bowlers are sometimes not delivering the ball with a flat, firm footing.

Studies investigating fast bowlers during actual competition are limited. Match heart rates of 116–131 (mean) and 174 $beats.min^{-1}$ (peak) have been reported (Gore et al., 1993; Brearley, 2003). Similarly, core temperature responses in matches have ranged between 38.0–39.5 ºC, while match sweat rates of 0.5 – 1.7 $kg.h^{-1}$ were related to the environmental conditions (environment 22 - 33ºC) (Table 2). In male fast bowlers there was a 4.3% reduction in body mass after two sessions (4 hours) of play on a warm day (27ºC) (Gore et al., 1993). These somewhat limited data reflect the logistical difficulties in monitoring fast bowlers during actual match play, thereby limiting the quantity of physiological data published to date.

Other investigations of fast bowlers during actual competition have focused on technique and accuracy. Using computerised ball tracking 'hawk-eye' technology,

bowling skill has been analysed through pitching lengths, bowling lines (width) and velocity (Justham et al., 2008). Fast bowlers exhibited only subtle differences in style between the different formats of cricket (Twenty20, One Day, and 5 day Test matches) (Justham et al., 2008). The variability of the bowling deliveries during a six over spell was also investigated using the hawk-eye system (Justham et al., 2006), unfortunately these two studies did not include any physiological measurements.

Spin bowling

There is limited research on the physical demands of spin bowling, with a small number of reports focusing on the technical aspects of spin bowling but not fitness. This is not surprising as the fitness requirements for spin bowlers appear to be minimal (i.e. relatively short, slow bowling run-up, combined with a highly skilled coordination of body parts that includes fine motor control of the fingers and hand). However spin bowlers bowl for prolonged periods (sometimes several hours) and fatigue particularly in challenging environmental conditions could impair bowling performance.

A case study has been published on Mutiah Muralitharan, the sport's most successful bowler (Lloyd et al., 2000). However the biomechanical analysis and kinematic model was developed to assess suspect bowling actions (with regard to throwing). Nevertheless, a comparison of elite versus sub-elite finger spin bowlers reported that during the off-break delivery, elite spinners impart greater spin (26.7 ± 4.6 $rev.s^{-1}$ versus 22.2 ± 3.8 $rev.s^{-1}$) and released the ball with a higher velocity (20.9 ± 1.7 versus 18.6 ± 1.2 $m.s^{-1}$) than sub-elite spin bowlers (Chin et al., 2009). A case study of a single off-spin bowler performing in different formats of cricket found the pace of the delivery increased by up to 0.89 $m.s^{-1}$ during limited over matches, however

the pitching length remained between 1.8 to 6.4 m and the pitching line was centered around a point 0.4 m to the left of the stumps, regardless of the type of match being played (Justham et al., 2008).

Using one elite leg (wrist) spin bowler the differences between four types of delivery (leg spin, wrong'un, slider and flipper) were investigated in the laboratory with high speed video analysis. Spin rates ranged between 19-31 $rev.s^{-1}$ while the speed ranged between 65-69 $km.h^{-1}$ (Cork et al., 2008). Future studies of spin bowling could investigate if increased spin can be imparted onto the ball via specific strength and conditioning programs that target increased grip strength and/or flexibility.

Fielding

Fielding, an activity every player undertakes is a critical component of cricket. Players generally have a favourite fielding role; there are specialist catchers (slips, short leg), in-fielders (covers, mid-wicket) and out-fielders or sweepers who patrol the boundary (third man, fine leg etc). The positional demands of various fielder types are likely to be very different depending on their role. In-fielders need speed, anticipation and agility, while out-fielders probably cover more distance in total and may have longer runs to cut off boundaries. Research into fielding has included a case study of the sliding stop fielding technique, focusing on the possible injury risk from incorrect performance of this skill (Von Hagen et al., 2000); an investigation showing that neither ball colour nor light level (within the range tested) affected slip-catching performance and movement initiation times in professional cricketers (Scott et al., 2000), and technique investigations of the overhead throwing skill (Cook and Strike, 2000; Bray and Kerwin, 2006). A time-motion analysis conducted using video-recordings of the cover-point position calculated that a daily distance of 15.5 km is

covered by first-class fielders (Rudkin and O'Donoghue, 2008). Table 1, shows that fielders will cover between ~2 - 6 km.h^{-1} in different formats of the game. However, comparisons between the specific workload of different fielding positions, or even between in-fielders and outfielders have yet to be performed.

Wicket-keeping

Wicket-keeping is arguably the most specialised position in cricket. Despite wicket-keepers having very specific movement characteristics and are involved in almost every piece of play, research into their fitness characteristics is virtually non-existent. The published research on wicket-keeping has focused only on anticipatory cue-utilization (Houlston and Lowes, 1990) and skill execution with different techniques (Unpublished report, Plunkett et al., 2006). There are no published studies examining the physical demands or fitness characteristics of wicket-keepers. This is surprising given the anecdotal claims and widely held view in the cricket community that wicket-keeping can be a strenuous and fatiguing position to play.

In competition, sweat losses of 0.3–1.4 L.h^{-1} have been reported for female cricketers, with a wicketkeeper exceeding a dehydration level of 2% of body mass (Soo and Naughton, 2007). With wicketkeepers having limited opportunities to consume drinks during a session (as they are not close to the boundary), studies investigating the relationship between skilled performance and hydration levels could provide useful insight into preventing dehydration-induced impairments in wicket-keeping performance.

The few time-motion studies conducted on wicketkeepers are summarised in Table 1, which shows a wicketkeeper typically covers between 2.5 – 4.8 km.h^{-1} in different

formats of cricket, with the distance covered sprinting being minimal (20 – 60 $m.h^{-1}$). The lack of sprints may reflect limited sprinting opportunities; the wicketkeeper is usually close to the stumps, where they are expected to be positioned when the fielders throw the ball in from the out-field.

2.3 Anthropometry of cricketers

Understanding anthropometric and strength attributes of elite athletes provides feedback for prescription of training programmes, and talent identification and development programs. An analysis of the anthropometric characteristics of elite fast bowlers reported the mean age (23.9 ± 3.5, 22.5 ± 4.5 y), body mass (87.9 ± 8.2, 66.2 ± 7.5 kg), height (1.88 ± 0.05, 1.71 ± 0.05 m) and sum of 7 skinfolds (62.3 ± 18.2, 98.1 ± 21.7 mm) for male and female national fast bowlers respectively (Stuelcken et al., 2007).

Anthropometric studies also provide evidence for pre-habilitation practices to minimise injury. A retrospective survey of female fast bowlers with and without a history of shoulder pain found that there were significant bi-lateral differences in external shoulder rotation range of motion ($p<0.05$) for the non-pain but not the pain group (Non-pain group: 89.1 ± 9.3 versus 83.2 ± 10.4º; pain group: 82.5 ± 13 versus 82.0 ± 10.9º, for the bowling and non-bowling shoulders respectively) (Stuelcken et al., 2008). A greater external range of motion may facilitate optimal throwing mechanics and minimise injury potential at the shoulder, by allowing a larger rotation range over which force can be generated during the acceleration phase of the throw. Physiotherapy screening tests could be used to identify which cricketers are at an

increased risk of injury, and ultimately facilitate prescription of prehabilitation and remedial exercises.

Other studies have correlated the anthropometric characteristics of elite cricketers (Portus et al., 2000; Pyne et al., 2006) with skilled performance, such as bowling speed. Fast bowlers with a larger and leaner upper torso bowl consistently faster than their smaller, less lean counterparts (Portus et al., 2000). Similarly, differences in peak bowling velocity between junior and senior bowlers relate primarily to body mass and upper-body strength, while lower body strength is a more important discriminator of the peak velocity between senior bowlers (Pyne et al., 2006). Determining the magnitude of strength differences and kinematic variables between bowlers of various speeds may enable strength and conditioning coaches to identify which exercises have the greatest transfer to bowling speed. Similarly, team and specialist bowling coaches are interested in identifying bowling techniques that enhance ball release speed; bowlers with a higher horizontal run-up velocity during the pre-delivery stride tend to bowl faster (Glazier et al., 2000). The run-up contributes up to 16% of ball release speed (Glazier et al., 2000) in fast bowlers. Other authors have supported (Elliott et al., 1986) and opposed (Portus et al., 2000) the notion that bowlers with a front knee angle at ball release of 150º or greater bowl faster.

2.4 Fitness levels of cricketers and fitness intervention studies

In 1996, the English and Wales Cricket Board (ECB) introduced a fitness advisory group to develop a battery of field tests to measure cricket-specific physical fitness. Adherence to this fitness battery across the 18 first-class counties was surveyed in

1997 (Fleming et al., 1997) - feedback from the counties indicated a perceived lack of specificity in the tests used. Fitness values for senior county cricketers have only recently been reported in the public domain (Johnstone and Ford, 2010), nine bowlers and six batsmen aged 25.0 ± 5.0 years were found to have sum of 7 skinfolds of 72.5 ± 16.5 and 65.5 ± 19.3mm; maximal oxygen uptake (predicted from multistage shuttle test) of 54.1 ± 2.8 and 56.1 ± 4.5 $ml.kg^{-1}.min^{-1}$; and cricket-specific pitch distance (17.7m) sprint times of 2.76 ± 0.6 and 2.77 ± 0.1 s, for batsmen and bowlers respectively. Over a decade ago, a study using a similar fitness battery investigated changes in physical fitness of three age groups (under 14, under 16 and under 19 years) of junior English cricketers before and after a 5-month cricket season. Notably the junior players failed to substantially improve their aerobic fitness during the season, but small improvements were noted in speed, agility and flexibility. These junior cricketers had estimated $\dot{V}O_2max$ values of 46.4 ± 5.9, 49.1 ± 4.7 and 53.1 ± 4 $ml.kg^{-1}.min^{-1}$, body mass of 47.1 ± 6.7, 70.7 ± 11.7, and 72.5 ± 6.8 kg, and sprint times of 3.03 ± 0.2, 2.71 ± 0.1, 2.65 ± 0.1 s to cover the cricket-specific pitch distance of 17.68m, for the under 14, under 16 and under 19 year old players respectively (Venning, Brewer, Stockill, 1999). From this limited insight, the under 16 and 19 cricketers are faster than the professional county cricketers but the county cricketers have a more developed aerobic system.

The cricket-specific run-of-three test (3 x 17.68 m) has also been used to compare batting equipment (different weights of leg guards), with times of 10.67 ± 0.48 to 10.69 ± 0.44 s for university level players (Loock et al, 2006). While the influence of a 0.55 kg difference in mass between models of leg guards had no substantial effect on turn speed or total run-of-three time, the run-of-three may not have had sufficient sensitivity to identify small difference in performance.

In a unique comparison, the fitness profile (leg press, bench press, 35m sprint, shuttle run, body fat) of South African players from the 1999 Cricket World Cup was compared with players from the 1999 South African Rugby World Cup team (Noakes and Durandt, 2000). While the rugby players were heavier and taller than the cricketers, there were no other substantial differences between the two groups, despite rugby having much greater physical demands. The national team cricketers (batsmen and bowlers respectively) had an estimated $\dot{V}0_2$max (~60 and 58 $ml.kg^{-1}.min^{-1}$), % body fat (13 and 13%), leg press (3.9 and 3.7 $kg.kg^{-1}$), bench press (1.0 and 1.0 $kg.kg^{-1}$) and 35m sprint time of (4.5 and 4.6 s). The cricketers' relatively high fitness measures may indicate high fitness levels benefit a player in selection into the international team or alternatively that the high fitness levels are required to deal with the physical (and touring) demands of the international game.

Similarly, the results of a fitness testing battery conducted on Australian international cricketers reported that a sample of male and female Test players had a mass of 85.8 ± 8.7 (mean ± SD) and 63.2 ± 7.3 kg; are 183.6 ± 7.9 and 169.7 ± 5.5 cm tall and a sum of seven skinfolds of 74.7 ± 25.1 and 96.1 ± 34.8 mm (Bourdon and Savage, 2000). These cricketers also had a vertical jump of 52.6 ± 9.5 and 41.3 ± 5.1 cm, a 20 m sprint time of 3.52 ± 0.2 s (female data only), can run a three in 9.65 ± 0.5 and 10.62 ± 0.5 s, and a mean estimated aerobic power of 51.4 and 47.4 $ml.kg.^{-1}min^{-1}$. Comparing the above two data sets, the Australian Test cricketers had between 6 – 8 $ml.kg.^{-1}min^{-1}$ lower mean estimated aerobic power, than their South African counterparts. While this may reflect differences between Test versus One Day players, it could also reflect the outcome of different training priorities and conditioning practices.

Evaluation of conditioning practices

A common practice across a number of sports is the evaluation of training practices in terms of how they replicate sport specific movement patterns. Sports including Australian Football (Dawson et al., 2004), rugby league (Gabbett, 2006) and tennis (Reid et al., 2008) have used this process to design more specific training drills. To date, there have been only limited studies investigating various aspects of cricket training activities.

Comprehensive studies have been undertaken detailing bowling (Dennis et al., 2003) and throwing (Saw et al., 2009) workloads of cricketers in both matches and in training, and how these workloads may relate to injury risks. In contrast, only a few intervention studies directed at enhancing either cricket bowling or throwing velocity have been conducted (Petersen et al, 2004; Freeston and Rooney, 2008). Studies directed towards injury prevention and/or performance enhancement provide coaches with practical guidelines to follow; however the application of these guidelines often requires coaches to break with or modify their traditional approach. In practice, often only the most innovative or experimental of coaches are willing to embrace a new approach.

Transferring the specific strength gains from training exercises into improved bowling speed is a key focus of strength and conditioning coaches. A controlled experimental design was used to investigate the effectiveness of training cricket fast bowlers over 10 weeks (total of 864 deliveries) using a combination of heavier and lighter balls (Petersen et al.,2004). The experimental group had a 2.7 km.h increase in bowling speed over the control group, however the chance of obtaining a practically beneficial change (defined as a minimally worthwhile change of 5 $km.h^{-1}$) was only

1%. Interestingly, one method of analysis estimated the magnitude of a possible worthwhile change in bowling speed is 2.5 $km.h^{-1}$ Before deciding to implement this training method, coaches should be aware that further study is required into the resultant change of accuracy. However, with recent improved technology of video based ball-tracking software (Hawkeye) the accuracy analysis is now easier for researchers to undertake.

How cricketers should actually perform strength training has been investigated with the performance effects due to the speed of lifting (Stewart, 2004). This study, compared the differences between an experimental group using a maximal concentric speed of lifting and a control group employing slow, heavy strength training (with no attempt at acceleration) during an 8-week, (2 session/week, 18 exercises) programme. The experimental group increased their bowling speed by 2.2 $km.h^{-1}$ more than the control group (n=12) (Stewart, 2004). While the body mass of the whole cohort was reported was 79.0 ± 10.6 kg, the subject characteristics (university level cricketers) including mass were not reported for each group. Nevertheless, the study provides practical recommendations for coaches to follow, additional studies are required to investigate and provide a sound scientific foundation for other training exercises and practices used with cricketers.

Similarly, the implementation of an 8-week progressive throwing program (60 throws per session, performed twice a week) showed that sub-elite cricketers could increase their mean (+6.6 %) and peak (+8%) throwing velocity more than a control group (Freeston and Rooney, 2008). Of interest, the changes in throwing velocity were correlated (r=-0.81) with initial velocity, showing that those players that threw faster at baseline improved less with training, suggesting a possible ceiling effect.

Other studies of conditioning practices have investigated the benefits of strength training targeting the abdominal muscles of cricketers with low back pain (Stanton et al., 2008; Hides et al., 2009). The experimental training groups increased the cross-sectional area of various abdominal muscles (transverse abdominis, internal oblique, multifidus) coupled with a 50% decrease in low back pain, in those cricketers that received the training (Stanton et al., 2008). However, there was no attempt to relate improved abdominal muscle strength to bowling performance measures. Studies directed at injury prevention would enhance their practical application (enhanced coach/athlete compliance) if performance enhancements were also evident.

Environmental effects

Cricket is a field sport played in summer conditions, with players frequently exposed to high ambient temperatures and humidity, often for days and hours on end. Cricketers' physical performance and motor skills (i.e. bowling velocity, line and length) can be compromised in the heat (Devlin et al., 2001) [~28°C and ~40% r.h.]; (Brearley, 2003) [~25°C and ~55% r.h]. While there has been a lot of work published about heat acclimation and heat acclimatization in general, there is very little published specifically on cricket. Known adaptations that enhance thermoregulatory control, should limit decrements in physical performance during cricket while simultaneously improving player comfort levels.

Short spells of pace bowling in warm conditions (acclimatisation) during an 8-day tournament (2003 Cricket Australia Interstate Challenge) can confer progressive cardiovascular adaptations (Brearley, 2003). However, it appears that specific heat acclimatisation for pace bowlers via a one-day tournament has negative consequences

(decline in bowling velocity and increase in ratings of muscle soreness) for bowling performances, perhaps due to inadequate recovery. With no control group it is unclear if these bowlers were adequately conditioned to bowl over multiple days, or whether it was the added heat exposure which increased their ratings of muscle soreness and impaired bowling velocity. Further work is required to resolve these issues and identify better ways to physically prepare players for training and games in hot conditions.

Core body temperature can rise 0.15°C per over bowled, to average 38.7°C following a short 4-over spell in warm conditions (Brearley and Montgomery, 2002). The peak core temperature recorded during the tournament (2003 Cricket Australia Interstate Challenge) was 39.5°C. It appears the demands of cricket fast bowling are substantially dependent on the environmental conditions, as under more extreme environmental conditions the potential heat strain on fast bowlers could be much greater. There is a potential for trainers to implement pre-cooling (before and during the breaks in an innings) and within match cooling strategies (e.g. cold towels or crushed ice drinks on the boundary).

Moderate levels of thermal stress have been reported in players competing in warm and humid conditions (Darwin, Australia) (Brearley and Montgomery, 2002), while playing cricket in hot conditions (Adelaide, Australia) easily elicits dehydration greater than 2% of body mass (Gore et al., 1993, which has been shown to be cause decrements in cognitive function (Soo and Naughton, 2007). Consequently, dehydration has the potential to adversely affect the tactical choices and player effectiveness in cricket play (given that cricket has a high reliance on decision making and cognitive function).

2.5 Conclusion

Several types of studies, including time-motion analysis, simulations and descriptive studies of elite cricketers have been used to enhance our understanding of the fitness requirements and match demands of cricket. To date, the studies have often been limited by a very small sample size of subjects (cricketers) related primarily to the time-consuming nature of the data collection process itself. The advent of commercially available GPS technology for monitoring movement patterns of athletes will allow time-motion studies with much larger and more representative samples. However the limitations of this technology do need to be understood as it relates to the movement demands specific to the game of cricket. To date, studies investigating specific cricket conditioning practices are rare, however with our increased understanding of the game requirements there is a need to compare contemporary training practices with actual game demands. Finally studies are required to investigate match demands under the various environmental conditions experienced across the cricket playing world.

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Chapter 3

Performance Analysis

Study 1: Analysis of performance at the 2007 Cricket World Cup

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Analysis of performance at the 2007 Cricket World Cup

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Abstract

Knowledge of the relative importance of team performance indicators in cricket helps determine team strategy and tactics. We analysed team, batting and bowling performances at the 2007 ICC Cricket World Cup Tournament to determine the magnitudes of differences between winning and losing teams. We compared the magnitudes of differences in key batting and bowling indicators between the qualifying Round Robin and the final Super 8 games. Magnitude of difference between teams was established with a standardised (Cohens) effect size (ES) with 90% confidence limits. The difference in performance indicators between winning and losing teams were smaller in the later (Super 8) stages of the tournament. The two performance indicators most highly correlated with winning in the Super 8 stage were taking wickets (ES=1.79±0.04 90%CL) and run rate (ES=1.39±0.02 90%CL). Hitting sixes had a greater influence during the earlier stage of the tournament; while bowling maiden overs was more important as the tournament progressed. The main contribution of this paper is that winning teams capture more wickets and have more 50-plus partnerships while maintaining a higher run rate primarily through hitting a higher percentage of runs in boundaries. Team selection should exploit these performance factors through selection of players most capable of delivering these objectives.

Keywords: batting, bowling, fielding, statistics, match strategy

1. Introduction

Performance indicators in cricket are extracted through notational analysis or rolling averages at a particular point in the game. Cricket is a sport in which statistics feature heavily and influence game strategy throughout the contest. Coaches use performance indicators post-game to assess both individual performance (for example, in batting, bowling and fielding) and overall team performance. While these indicators are in widespread use there is little published empirical data indicating their importance or usefulness in international cricket. The weighting that the coach places on these performance indicators dictates subsequent team strategy. Team strategy is evident in many facets within the game, including how quickly to chase a total or how aggressively a bowler looks to obtain wickets as opposed to restricting runs. It is important to determine which performance indicators are most highly correlated with competitive success; this knowledge should underpin team strategies resulting in a higher likelihood of success.

Performance indicators in cricket fall into three main categories: general game indicators, batting and bowling. Previous modelling of the 1999 (England) and 2003 (South Africa) ICC Cricket World Cups demonstrate that teams do not get a significant advantage by winning the coin toss or batting first (Allsop, 2005). Significant advantage due to a particular variable in team sport refers to the phenomenon that teams displaying the variable win significantly more often than chance would dictate. In games such as cricket where all matches (seldom do matches result in a tie) involve a win / loss result, the advantage of a particular variable may be defined as 'the consistent finding that the team displaying the particular variable more frequently than the opposition wins over 50% of the time (Morley and Thomas, 2005).

Success in cricket is all about scoring more runs than your opposition, however there are many different ways to go about this task. Cricket batsmen can accumulate runs in a relatively safe manner by taking few risks, maximising controlled deflections and limiting aerial shots. Alternatively batsmen can play more risky shots to capitalise on hitting more balls to the boundary; this may involve pre-meditating certain shots and hitting more balls in the air. Some batsmen are suited to playing a more aggressive style while others are more orthodox accumulators of runs. Irrespective of the batting strategy it is commonly suggested that the key to a teams batting success is batting in large partnerships. Performance indicators reflecting the composition of a team's innings in terms of how the runs are scored and the number of 50-run plus partnerships are used to determine the particular batting strategy employed.

Bowling strategy revolves around restricting runs. There are two main methods to restrict the opposition teams' runs. Firstly, bowlers can bowl a tight line and length, and when combined with a well placed field, the scoring opportunities for batsmen are limited. An alternative approach is to bowl more aggressively to try and take wickets. This approach works by either bowling out the opposition before their allocated 50-overs or by capitalising on the new batter requiring a settling in period where their scoring rate is lower while they become familiar with the pitch conditions and bowling attack. Bowling strategy also is influenced by the type of bowlers used with some teams preferring to employ only fast bowlers while other teams will use a combination of fast and spin bowlers. Indicators of the particular bowling strategy employed include; the number of wickets taken, the number of maiden overs bowled and the number of overs bowled by spin bowlers.

A criticism of this and previous World Cups was the large difference in playing standard between the top (the traditional 10 test playing nations) and lower ranked qualifying nations. Given 16 teams made up the Round Robin stage of the tournament it is logical to assume a larger variety of playing standards between these nations. Separate analysis of qualifying and final stages helps to answer the question of whether the tactics used in the later stages (when teams are more similarly matched for ability) of the tournament differs to those displayed in the Round Robin stage.

The purpose of this study was to quantify the magnitude of differences between winning and losing teams at the 2007 International Cricket Council (ICC) Cricket World Cup in key team, batting and bowling indicators of performance. We also sought to compare

these differences during the initial qualifying or Round Robin stage of the ICC World Cup with the final Super 8 games.

2. Methods

The format of the 2007 ICC Cricket World Cup consisted of 16 teams playing four distinct rounds (a Round Robin, Super 8, Semi Finals and Final). The Round Robin stage comprised a total of 24 games played between four groups of four teams. The top eight teams (two from each group) progressed to the Super 8s stage, where each team played each other team once (points were carried forward from the game involving the other team that progressed from the same pool). At the conclusion of these 24 games, the four top placed teams progressed to the semi final stage with the first placed team playing the fourth placed team and the second and third placed teams playing against each other. The winners of the two semi finals progressed to the last stage of the tournament: the final. For the purposes of our analysis, we analysed 23 games in the Round Robin (the tied game between Ireland and Zimbabwe was excluded) and all 24 games of the Super 8 stage.

The immediate pre-tournament ICC International One Day Cricket rankings were used to determine which team was the favourite for each game. Simple descriptive statistics were used to code a number of discrete game variables including; the favourite winning, winning the toss, batting first, hitting more 6's, more 4's, more runs coming from the accumulated value of boundaries, running more singles, taking more wickets, bowling a greater number of maiden overs, bowling more spin overs or having a greater number of fifty plus partnerships than the opposition. For the winning team only, these variables were expressed in binary code of either 1= yes, or 0= no. Dividing the number of games by the summated total of the binary digits generated a percentage that the particular variable occurred for the winning team.

We adopted the approach of magnitude-based inferences to analyse the World Cup data (Batterham and Hopkins, 2006). The effect size statistic was generated for the absolute differences in each variable to assess the magnitude of difference between winning and losing teams. This analysis allows the relative importance of different variables to be assessed in terms of their importance in contributing to a successful match outcome. Effect sizes were established as follows (ES = change in x / SD (difference in mean / pooled SD)). Briefly the criteria for interpreting effect size were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, and > 2.0 very large (Hopkins, 2004). Effect sizes were ranked from the highest to the lowest to identify which performance indicators were most closely associated with successful performance at the World Cup.

3. Results

The general match variables (overs batted, runs made, run rate and wickets taken) of the winning and non-winning teams in the Round Robin and Super 8 stage of the tournament are presented in Table 1. The average winning margin in the round robin stage was 164 ± 80 runs for sides that batted first or 6 ± 2 wickets for winning sides that batted second. In comparison, during the Super 8s stage the winning batting margin was

reduced to 102 ± 50 runs, while the winning bowling margin was similar at 6 ± 3 wickets.

The favourite won a similar proportion of games with 78% and 83% during the Round Robin and Super 8 stages respectively. During the Round Robin stage of the tournament, teams winning the toss only decided to bat first 21% of the time. This contrasts with the Super 8 stage where the team winning the toss batted first 38% of the time. Teams that won the toss in the Round Robin stage ended up winning the game 38% of the time, compared to teams in the Super 8 stage who won the game 54% of the time after winning the toss.

Table 1. General game variables (± SD) of winning and non-winning teams.

Stage	Team	Overs Batted	Runs Made	Run Rate	Wickets Taken
Round Robin	Winning	43.3 ± 10.0	262 ± 90	6.0 ± 1.5	9 ± 1
	Non-Winning	41.6 ± 10.0	168 ± 52	4.1 ± 0.8	5 ± 2
Super 8's	Winning	40.8 ± 13.7	222 ± 75	5.7 ± 1.3	9 ± 1
	Non-Winning	42.7 ± 8.8	182 ± 57	4.2 ± 0.8	5 ± 3

The composition of how winning and non-winning teams scored their runs is presented in Table 2. In both, rounds of the tournament the winning team scored a higher percentage of their runs from boundaries and had a higher number of 50-plus run partnerships.

Table 2. Batting variables (± sd) of winning and non-winning teams

Team	6's	4's	1's	% 4's & 6's	% runs from 1's	50+ run p'ships
Round Robin						
Winning	7.2 ± 5.7	23 ± 8	77 ± 27	51 ± 12	29 ± 5	2.0 ± 1.0
Non-Winning	2.1 ± 1.6	15 ± 6	59 ± 25	45 ± 9	34 ± 8	0.8 ± 0.7
Super 8's						
Winning	3.3 ± 2.9	18 ± 7	74 ± 32	43 ± 11	32 ± 9	1.8 ± 0.9
Non-Winning	2.1 ± 1.5	14 ± 6	69 ± 25	36 ± 7	38 ± 7	1.0 ± 0.8

In terms of bowling the winning team bowled less spin overs and a greater number of maiden overs (Table 3). In comparison to the opposition, the winning team bowled less wides and no balls 61% of the time during the round robin, compared to only 52% less wides and no balls in the super 8 stage.

Table 3. Bowling variables (± sd) of winning and non-winning teams

Team	Spin overs	Maidens bowled
ROUND ROBIN		
Winning	11.3 ± 6.8	3.4 ± 2.4
Non-Winning	13.2 ± 7.5	1.7 ± 1.7
SUPER 8's		
Winning	10.9 ± 7.1	3.8 ± 2.3
Non-Winning	11.4 ± 6.5	1.6 ± 2.1

A key aspect of this study was the magnitude of difference in key performance indicators between winning and losing teams, and between the initial (Round Robin) and latter (Super 8) stages of the ICC World Cup (Table 4). These tables highlight which variables successful teams were more dominance in, and the magnitude of that dominance. The biggest difference between winning and losing were the greater number of wickets taken by the winning (bowling) team, followed by the batting indicators of run rate and 50+ partnerships. In general the magnitude of difference in performance indicators between winning and losing teams was smaller in the Super 8 stage compared with the initial Round Robin games

Table 4. Effect size (± 90% CL) of selected performance variables between the winning and losing teams during the Round Robin and Super 8 stages. The positive effect size values indicate the winning team had a better or higher score, while the negative effect size values indicate the losing team had a better or high score.

Round Robin		Super 8		
Performance variable	Effect Size	Performance variable	Effect size	Rating
Wickets	2.53 ± 0.03			Very large
Run rate	1.72 ± 0.02	Wickets	1.79 ± 0.04	
50+ partnerships	1.44 ± 0.02	Run rate	1.39 ± 0.02	Large
Runs	1.28 ± 1.36			
6s	1.22 ± 0.08			
4s	1.11 ± 0.13	Maidens	1.00 ± 0.04	
Maidens	0.82 ± 0.04	50+ partnerships	0.94 ± 0.02	
1s	0.69 ± 0.48	4s	0.76 ± 0.12	Moderate
		% runs from boundaries	0.75 ± 0.16	
		Runs	0.60 ± 1.21	
% runs from boundaries	0.57 ± 0.20	6s	0.52 ± 0.04	Small
Overs	0.17 ± 0.19	1s	0.17 ± 0.52	
		Spin overs bowled	-0.07 ± 0.12	Trivial
		Overs	-0.17 ± 0.21	
Spin overs bowled	-0.27 ± 0.13			Small (-)
% runs from 1s	-0.66 ± 0.12	% runs from 1s	-0.68 ± 0.15	Moderate (-)

4. Discussion

Identifying the performance indicators that are most highly correlated with a successful match outcome provides the basis for developing and implementing individual player and team strategies. The major differences between winning and losing teams across the tournament are wining teams take more wickets and maintain a higher run rate, while losing teams score a higher proportion of their runs from singles. Additionally during the Round Robin stage 50-plus partnerships, total runs and the number of 6's hit also have a large magnitude of difference between winning and losing teams, however the magnitude of these differences are less in the Super 8 stage of the tournament. During the Super 8 stage bowling maiden overs becomes more important however taking wickets and maintaining a high run rate when batting are still the highest correlated performance indicators to success. These findings should be useful for coaches and support staff at the international and other levels of cricket in planning for one day tournaments.

General game indicators show that winning the toss in the round robin stage of the tournament was actually a disadvantage with teams surprisingly reluctant to bat first (only 21%) ironically the team that batted first actually ended up winning 61% of the time. In the Super 8 stage toss winning captains increased their likelihood of batting

first (to 38%) but still the predominant decision was to bat last – during the Super 8 stage teams that batted first went on to win the game only 42% of the time this may indicate that the Captains were better at making the right decision in the Super 8 stage. This observation is supported by the toss winning captains in the Super 8 stage winning the game 54% of the time, compared to only 38% in the round robin stage.

Successful batting strategy across the tournament indicates that it is important to hit a high proportion of boundaries. It is interesting to note that while individually the magnitude of 6s, 4s and singles hit decreased in the Super 8 stage, the magnitude difference in proportion of runs scored from boundaries increased reflecting possibly less twos and threes being run. Teams therefore need to focus on scoring boundaries as often as possible and not be content with accumulating singles; this pattern of scoring may be related to the smaller West Indian grounds. Similarly preserving wickets, and having batsmen capable of scoring with a high run rate and having more 50-plus partnerships when batting enhances the chance of winning.

Bowling became more important as the tournament progressed, with an increase in the magnitude of the effectiveness of maiden overs however taking wickets remained the key factor in determining success. Because the percentage of runs from singles was negatively correlated with success, forcing the opposition to have a higher percentage of runs in singles will enhance the fielding team's chance of success. Utilising spinners during the Round Robin stage was actually a small disadvantage to the bowling side, however during the Super 8 stage the use of spinners had a trivial effect on performance. It could be speculated that the lower quality of spinners in some of the teams competing in the Round Robin stage of the tournament lead to the negative association with success. Spinners may have also been disadvantaged in the West Indies with the smaller grounds offering batsmen more chance of clearing the boundary rope.

The magnitudes of difference in performance indicators between winning and losing teams were smaller in the latter stages of the tournament. Across the tournament the two most highly correlated performance indicators to match success were taking wickets and run rate with effect sizes of 2.53 and 1.79 (wickets), 1.72 and 1.39 (run rate) and in the Round Robin and Super 8 stages respectively. During the round robin stage of the tournament the four performance variables that were correlated highest with a successful outcome from (highest correlation to lowest) were; wickets taken, run rate, 50+ partnerships and total runs. While during the Super 8s stage the four performance variables correlated highest with a successful outcome were; wickets taken, run rate, maiden overs bowled and 50+ partnerships.

In conclusion winning teams capture more wickets and have more 50-plus partnerships while maintaining a higher run rate primarily through hitting a higher percentage of runs in boundaries. We consider that team strategies should be based on objective analysis of the contemporary game at the benchmark level of the ICC World Cup. With this knowledge coaches and players can develop, implement and exploit performance factors most highly associated with success, an approach also used in Rugby Union (Prim *et al.*, 2006). Team strategy can be influenced by batting strategy, bowling and fielding placement and through selection of players within the squad most capable of delivering the performance objectives. Teams should focus on attacking bowlers

capable of taking wickets and not just restricting runs. With run rate the second most important indicator it is important to have batsmen capable of scoring quickly, equally while fielding; restricting run rate by bowling maiden overs becomes more important as the tournament progresses. The one day international form of cricket continues to evolve so this type of performance analysis will need updating at regular intervals.

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Chapter 3

Performance Analysis

Study 2: Analysis of Twenty/20 Cricket performance during the 2008 Indian Premier League.

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Analysis of Twenty/20 Cricket performance during the 2008 Indian Premier League

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Abstract

Team strategy and tactics in cricket can be influenced by knowledge of the relative importance of team performance indicators. We analysed team, batting and bowling performances at the 2008 Indian Premier League Twenty/20 Tournament (IPL) by comparing the magnitudes of differences in key batting and bowling indicators between winning and losing teams. Magnitude of difference between teams was established with a standardised (Cohen's) effect size (ES:0.2) with 90% confidence limits. There were several moderate or large differences in performance indicators between winning and losing teams in the IPL. The three best indicators of success in the IPL were taking more wickets in the game (ES=1.93±0.04 90%CL), taking more wickets in the last 6 overs (ES=1.01±0.03) and having a higher run rate (ES=0.96±0.02). Winning teams captured more wickets particularly in the first and last six overs, and were more effective in containing the opposition teams' run scoring in the middle eight overs. When batting, winning teams tended to face less dot balls and score more runs from 25+ run partnerships. Team tactics should focus on wicket-taking bowling and field placements in the first and last six overs, and run restrictive field placing and bowling in the middle eight overs.

Keywords: batting, bowling, fielding, statistics, match strategy, tactics.

1. Introduction.

The sport of Cricket is in the midst of a revolution. The latest version of cricket, Twenty/20 (T20) is rapidly increasing in popularity, due largely to the huge cash injection and media publicity surrounding the franchised-based club competitions taking place around the world. The world's richest franchise based T20 competition is the Indian Premier League (IPL), owned and administered by the Board of Control for Cricket in India (BCCI). Prior to the inaugural tournament, the BCCI made close to 1.75 Billion USD from the sale of TV rights ($908 million), promotion ($108 million) and franchises ($728 million) (Cricinfo, 2008a). Players are earning unprecedented salaries, with the highest paid players earning up to $100,000 USD per game. With so much money invested in the game, franchise owners, management teams and coaches would be wise to apply successful game tactics, and select players most capable of executing a proven game strategy.

In T20 each team faces 20 six-ball overs, with fielding restrictions (only 2 fielders are allowed outside the 30 yard circle) applying in the first six overs in each innings. There is limited scope for error with one or two overs potentially influencing the overall match outcome. Effectively the team captain's manipulation of field placements and bowler rotations, each batsman's modification of innings tempo and each cricketer's overall skill execution, influences the game outcome to various extents. To date there is limited published data on T20 cricket. One comparative study of bowling tactics has been undertaken using only three right arm bowlers (a fast bowler, a medium paced bowler and a off-spin bowler) playing all three types of cricket; Test match, 50 over cricket and T20. The authors found that despite the batsmen's playing style becoming more aggressive with the shorter the version of the game; the bowlers did not alter their bowling style (Justham et al., 2008).

A few analytical studies have been conducted using 50 over cricket including a study by Cohen (2002) that investigated the winning chances of teams by utilising career bowling figures to determine each team's probability of dismissing the opposition, combined with each batsman's career average run scoring to predict the likely team score. While Gray and Le (2002) developed a model for 50 over international cricket that utilises overs and wickets remaining combined with runs scored so far to forecast the total score of a team that bats first during a game. Their model can also be applied during the second innings to determine the probability of the team batting second winning the match. Finally, the magnitudes of performance indicators in 50 over international cricket in the 2007 World cup have been recently published (Petersen et al., 2008) however the dynamics of T20 is widely considered to be different to 50-over cricket. Clearly, winning teams score more runs and take more wickets but which is more important, and how a fielding captain may optimally use his bowling options is not known. Knowledge of the relative importance of T20 specific team performance indicators (TPIs) is needed to objectively develop team strategies.

The purpose of this study was to quantify the magnitude of differences between winning and losing teams at the 2008 IPL in key team, batting and bowling indicators of performance. We also sought to compare the relative importance of published performance indicators in 50-over cricket with those from T20.

2. Methods

The format of the 2008 Indian Premier League T20 competition consisted of a round robin stage with the eight teams playing each other on a home and away basis (14 games per team). At the conclusion of these 56 games, the four top placed teams progressed to the semi final stage with the first placed team playing the fourth placed team, and the second and third placed teams playing against each other. The winners of the two semi finals progressed to the final. For the purposes of our analysis, we analysed 56 of the 59 games in the IPL (the two rain affected games decided by the Duckworth-Lewis system and the abandoned match were excluded from the analysis). Match data was obtained from both the ball by ball written commentary and match score cards published by the Cricinfo website (Cricinfo, 2008b). When it was unclear from the written commentary, players were characterised as spin bowlers by referring to the published player profiles (Cricinfo, 2008b).

Magnitude-based inferences (Batterham and Hopkins, 2006) were used to characterise differences in selected batting and bowling variables in the IPL including; hitting more 6's, more 4's, more runs coming from the accumulated value of boundaries, running more singles, taking more wickets, bowling a greater number of maiden overs, bowling more spin overs, or having a greater number and value of more than 25 run partnerships than the opposition. The effect size statistic was generated to assess the magnitude of difference between winning and losing teams. This analysis allows the relative importance of different variables to be compared. Effect sizes were established as follows (ES = change in x / SD (difference in mean / pooled standard deviation)). Briefly the criteria for interpreting effect sizes were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, and > 2.0 very large (Hopkins, 2004). Effect sizes were ranked from the highest to the lowest to identify which performance indicators were most closely associated with successful performance at the IPL.

3. Results

During the IPL there was a slight home advantage with the home team winning 55% of games across the tournament. However, there was no advantage of winning the toss with 50% of these sides also winning the game. Captains winning the toss decided to field first 57% of the time, while the team that fielded first won 61% of games.

The general match variables (overs batted, runs made, run rate and wickets taken) of the winning and non-winning teams in the IPL tournament are presented in Table 1. During the IPL winning teams faced 6% less balls and made 9% more runs, equating to an 18% higher run rate and also took twice as many wickets as losing teams.

Table 1. General match, batting and bowling variables (± sd) of winning and non-winning teams. Data is presented as frequency of events per innings.

	Winning teams	Non-winning teams
General match variables		
Balls faced (n)	110 ± 17	117 ± 8
Runs made (n)	163 ± 33	150 ± 31
Run rate (runs/over)	9.0 ± 1.4	7.6 ± 1.4
Wickets taken (n)	8 ± 2	4 ± 2
Batting variables		
6's	5.9 ± 3.4	4.9 ± 2.6
4's	16 ± 4	14 ± 4
1's	40 ± 10	42 ± 8
% runs from 4's & 6's	60 ± 9	56 ± 7
% runs from 1's	25 ± 6	28 ± 5
25+ run partnerships (n)	2.3 ± 0.9	2.3 ± 1.0
Value of 25+ run partnerships (runs)	130 ± 42	98 ± 42
Bowling variables		
Spin overs (n)	4.3 ± 2.4	4.5 ± 2.3
Maidens bowled (n)	0.2 ± 0.4	0.1 ± 0.3
Wides bowled (n)	3.7 ± 2.0	4.2 ± 2.2
No balls bowled (n)	0.7 ± 0.9	0.7 ± 1.0

Table 2. Magnitude of difference (reported as effect size ± 90% CL) in selected performance variables between the winning and losing teams during the 2008 IPL. The positive effect size values indicate the winning team had a more favourable outcome, while the negative effect size values indicate the losing team were better.

Performance variable	Effect Size	Rating
Wickets	1.93 ± 0.04	Large
More wickets taken in last 6 overs	1.01 ± 0.03	Moderate
Run rate	0.96 ± 0.02	
More wickets taken in first 6 overs	0.81 ± 0.01	
Less dot balls (when batting)	0.80 ± 0.16	
Value of 25+ partnerships	0.75 ± 0.71	
Less Runs conceded middle 8 overs	0.68 ± 0.21	
Less Runs conceded first 6 overs	0.56 ± 0.21	Small
4s	0.52 ± 0.07	
% Runs from boundaries	0.51 ± 0.12	
More wickets taken in middle 8 overs	0.47 ± 0.02	
Lower % runs from boundaries middle 8 overs	0.46 ± 0.21	
Higher opening partnership	0.46 ± 0.37	
Runs	0.42 ± 0.53	
Lower % runs from boundaries first 6 overs	0.39 ± 0.23	
Maidens	0.34 ± 0.00	
6s	0.30 ± 0.04	
Less bowlers used (when fielding)	0.27 ± 0.01	
Less wides (When fielding)	0.25 ± 0.04	
Lower % runs from boundaries last 6 overs	0.25 ± 0.29	
More bowling changes	0.06 ± 0.04	Trivial
Less no balls (when fielding)	0.04 ± 0.02	
Number of 25+ partnerships	0.02 ± 0.02	
Less Runs conceded last 6 overs	-0.08 ± 0.40	
Spin overs bowled	-0.11 ± 0.04	
1s	-0.22 ± 0.13	Small (-)
Balls faced	-0.44 ± 0.13	
% Runs from 1s	-0.65 ± 0.08	Moderate (-)

Briefly the criteria for interpreting effect size were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, and > 2.0 very large (Hopkins, 2004). Effect sizes were ranked from the highest to the lowest to identify which performance indicators were most closely associated with successful performance at the 2008 IPL tournament.

The composition of how winning and non-winning teams scored their runs in the IPL is also presented in Table 1. Winning teams hit 20% more sixes, 14% more fours and

scored 5% less singles than the non-winning teams. Notably, the winning teams also scored 33% more runs in 25+ run partnerships. While winning teams took twice as many wickets as non-winning teams both teams bowled a similar number of spin overs. Furthermore, winning and non-winning teams bowled a similar number of wides, no balls and maiden overs.

A key aspect of this study was the magnitude of difference in key performance indicators between winning and losing teams (Table 2). This Table lists in rank order which variables successful teams were more dominant in, and the magnitude of that dominance. The biggest difference between winning and losing was the greater number of wickets taken by the winning team, followed by the bowling indicator of taking more wickets in the last six overs.

4. Discussion

Identifying the cricket performance indicators highly correlated with a successful match outcome provides the basis for developing and implementing individual player and team strategies. The major differences between winning and losing teams in the 2008 IPL tournament were that winning teams took more wickets and maintained a higher run rate, while losing teams scored a higher proportion of their runs from singles. These findings should be useful for coaches and support staff at the international and other levels of cricket in planning for Twenty/20 tournaments. In particular, coaches should target coaching strategies for individual bowlers to take more wickets or batsmen to increase their run scoring rates.

Analysis of general game indicators show that winning the toss held no advantage in deciding the overall game outcome. Toss winning captains favoured fielding first, which seemed to hold a slight advantage as indicated by 61% of teams fielding first winning. The increased amount of dew after dark and the resulting difficulty of bowling with a slippery ball may have contributed to the captain's favouring to field first. Alternatively, captains may have felt that the team fielding second is more fatigued in the field after their batting innings. Irrespective of the reason, it is interesting that Allsopp and Clarke (2002) also found evidence of teams gaining an advantage by batting last in the longest form of Cricket, Test cricket.

The results from the 2008 IPL suggest that the most successful batting strategy involves retaining wickets, particularly in the first and last 6 overs. Additionally, retaining wickets helps to score more runs in partnerships. Accumulating more runs in 25+ run partnerships has a moderate effect in winning. Winning teams also score more heavily in the middle 8 overs and score from a greater number of deliveries (face less dot balls). Team selection should look at picking specialist batsmen that can survive the opening bowlers attack in the first 6 overs while also scoring boundaries. Batsmen in the middle eight overs need to be able to accumulate runs while maintaining a focus on hitting boundaries, particularly fours (non-winning teams score a higher proportion of their runs from singles). In the last 6 overs there are only trivial differences between winning and non-winning teams in the amount of boundaries scored, indicating little difference in the batting strategy at this stage of the game. Scoring more boundary fours has a greater correlation to winning than scoring more boundary sixes; this may be related to the increased risk of losing wickets with trying to hit over the boundary rope too often.

The results here suggest that the most successful bowling strategy is to focus on taking wickets particularly in the first and last six overs. Specialist bowlers most capable of taking wickets should be utilised during these periods of the game. Bowlers that are more defensive and harder to score from should be employed in the middle eight overs. Teams that used fewer bowlers had a small advantage, indicating that teams forced to utilise part-time bowlers may be at a disadvantage. Teams that had a greater number of overs bowled by spinners neither increased or decreased their chance of game success**.** Spinners (like any other type of bowler) should aim to restrict runs particularly in the middle eight overs and focus on taking wickets in the first or last six overs. Most captains tended to introduce their spin bowlers after the first six overs when the fielding restrictions were relaxed, indicating that the spinners primarily undertook a run-restricting role. Additionally, the number of bowling changes that a captain made had no substantial effect on the chance of winning. Both winning and non-winning teams averaged nine bowling changes during the innings, therefore bowlers must be prepared at times to bowl one over spells. Skill execution and discipline are crucial; teams that produce more maidens and bowl fewer wides have a small advantage in the chance of winning.

It is interesting that comparing the winning teams in the IPL to those in 50-over cricket (Petersen et al., 2008); IPL winning teams faced only 45% of the deliveries yet they made 73% of the runs, this equated to a 58% higher run rate in IPL. Additionally, IPL winning teams hit 79% more boundary sixes, yet hit 11% less boundary fours and 46% less singles the winning teams in the Super 8 stage of the 50-over World Cup. Notably, taking wickets was also the highest performance indicator of success in 50-over cricket. In 50-over cricket the next two highest performance indicators of success are having a higher run rate and a greater number of 50+ partnerships, whereas in the IPL, the next two highest indicators are taking wickets in the last 6 overs and run rate.

This paper compared winning versus losing teams; however alternative approaches can highlight specific tactics of particular teams. One method is to compare the performances of the semi finalists to those of the other teams, while a more thorough approach is to address what is typical against a particular type of opposition utilising a matrix of comparisons. This could include comparisons of top 4 versus top 4 placed teams, bottom 4 versus bottom 4 placed teams and top 4 versus bottom 4 placed teams. These comparisons may help a particular team refine their tactics for a particular opposition and should be investigated by the team's support staff.

In conclusion, despite the shorter versions of cricket favouring batsmen (no bouncers, free hits for no balls etc.) bowlers have a greater influence on the game outcome. Team selection should include having quality wicket-taking bowlers and utilising these bowlers in the first and last six overs. Common sense dictates that batsmen need to score quickly, however they should focus on batting in partnerships and target scoring boundary fours, as opposed to targeting the riskier boundary six options too often. Team selection should focus on selecting batsmen that have high strike rates (runs scored divided by balls faced), in particular a high ball scoring percentage (balls scored from divided by total balls faced). Teams should also look to recruit batsmen that have a low percentage of runs scored from singles. T20 cricket is still evolving; and coaching staff should focus on improving wicket-taking strategies as this has the largest influence on success. Two potentially useful strategies that need evaluating are the type of bowling deliveries associated with the highest wicket-taking success rates and the amount of

variation that bowlers should employ to restrict runs. Team tactics should focus on wicket-taking bowling and field placements in the first and last six overs, and run restrictive field placing and bowling in the middle eight overs.

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Chapter 4

Validation of GPS Technology

Study 3: Validity and reliability of GPS units to monitor cricket-specific movement patterns.

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Validity and Reliability of GPS Units to Monitor Cricket-Specific Movement Patterns

Carl Petersen, David Pyne, Marc Portus, and Brian Dawson

Purpose: The validity and reliability of three commercial global positioning system (GPS) units (MinimaxX, Catapult, Australia; SPI-10, SPI-Pro, GPSports, Australia) were quantified. ***Methods:*** Twenty trials of cricket-specific locomotion patterns and distances (walking 8800 m, jogging 2400 m, running 1200 m, striding 600 m, sprinting 20- to 40-m intervals, and run-a-three) were compared against criterion measures (400-m athletic track, electronic timing). Validity was quantified with the standard error of the estimate (SEE) and reliability estimated using typical error expressed as a coefficient of variation. ***Results:*** The validity (mean ± 90% confidence limits) for locomotion patterns walking to striding ranged from 0.4 ± 0.1 to 3.8 ± 1.4%, whereas for sprinting distances over 20 to 40 m including run-a-three (approx. 50 m) the SEE ranged from 2.6 ± 1.0 to 23.8 ± 8.8%. The reliability (expressed as mean [90% confidence limits]) of estimating distance traveled by walking to striding ranged from 0.3 (0.2 to 0.4) to 2.9% (2.3 to 4.0). Similarly, mean reliability of estimating different sprinting distances over 20 to 40 m ranged from 2.0 (1.6 to 2.8) to 30.0% (23.2 to 43.3). ***Conclusions:*** The accuracy and bias was dependent on the GPS brand employed. Commercially available GPS units have acceptable validity and reliability for estimating longer distances (600–8800 m) in walking to striding, but require further development for shorter cricket-specific sprinting distances.

Keywords: accuracy, precision, tracking

Quantifying movement patterns based on game demands is important in developing sport-specific conditioning programs and tailoring the length of recovery periods from game and training activities. Most commonly, this practice has been undertaken through time–motion studies conducted in real time with pen, paper, and stopwatch (notational) or postgame utilizing video recordings with or without customized computer analysis (digitizing). Time–motion analysis has been conducted in a number of sports, including basketball,[1] field hockey,[2] futsal,[3] handball,[4] ice hockey,[5] rugby,[6–8] soccer,[9,10] taekwon-do,[11] and tennis.[12] The time–

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motion analysis process has traditionally been very time intensive as digitizing takes approximately 8 h to produce data for one player for a whole 80-min rugby match.[13] Although a high degree of validity (~2% typical error) has been reported for estimation of total distance,[6,13] time–motion analyses can also have poor comparability between notational and digitizing methods, with one study reporting a 27.5% difference in estimating time spent in work.[13]

The extended game duration and large playing field in cricket makes it difficult to conduct time–motion studies with pen and paper or video recordings. Accordingly, to date there is only one time–motion study examining batting requirements[14] and one study on the fielding requirements of cricket.[15] While these studies[14,15] divided the fielding and batting requirements of cricket into components (standing, walking, jogging, striding, sprinting, playing a shot, and lateral motion), the authors only reported temporal data with no estimates of distances covered in each movement category. With a lack of field markings, accurate measures of distance are difficult to obtain with some forms of time–motion analysis—hence the need for GPS as opposed to time–motion analysis.

Recently improved miniaturization and enhanced battery life have made global positioning system (GPS) athlete-tracking units a more convenient, less time-consuming, and increasingly popular method to quantify movement patterns and physical demands in sport. Global positioning system technology has been used to quantify the physiological demands of athletes training and/or competing in events such as horse racing,[16,17] orienteering,[18] triathlon,[19] Australian football,[20] Gaelic football,[21] rugby,[22] and soccer.[23] These studies have employed several different commercially available GPS brands, including Fidelak Equipilot,[16] Polar,[17] Garman Forerunner,[18] GPSports,[20,21] and FRWD.[23] However, currently in elite cricket there are only two brands of GPS unit in regular use (MinimaxX and GPSports). To date, only one study[24] using the MinimaxX GPS unit has been published. A comparison was undertaken of four different tennis drills performed on a tennis court with six repetitions of 30- and 60-s work periods. The authors used distance covered and movement speed as measures of intensity, yet surprisingly no reliability data were reported. Another study[20] investigated the validity of the GPSports SPI-10 unit, finding that it overestimated distances by a mean of 4.8%. However, the distances used only ranged from 128 to 1386 m, whereas it is likely that some cricket players cover distances at least 10-fold greater (~10,000 to 15,000 m). Furthermore, no account of possible variations in the accuracy of different movement velocities was reported. Coutts and Duffield[25] compared different movement velocities between three different GPS models (including the GPSports SPI-10) from the same manufacturer and reported a typical error (test–retest reliability) of 5.3% in estimating the distance covered in low-intensity activity. However, the walking component of each 130-m lap was only 14 m. In cricket, walking forms up to 90%[26] of total movements, and, given that an innings typically lasts 3.5 h, walking needs to be assessed over an extended duration.

A recent study[27] used a 487-m lap repeated 14 times (total circuit distance = 6818 m) with movement patterns simulating field hockey match play to assess validity of the GPSports SPI Elite 1-Hz GPS unit. The authors used only one unit and reported the validity of distance and mean speed for four types of hockey-specific shuttles, total lap distance, and overall total distance. Although significant differences ($P > .01$) were found from the criterion distance during the hockey-

specific shuttles (from a mean underestimation of 1.2% to an overestimation of 0.8%), the mean lap distance and total circuit distance were not significantly different from the criterion distance (mean overestimation of 0.04 and 0.06% respectively). What remains unknown from this investigation is the validity and reliability of the individual movement patterns (walking, jogging, cruise, sprint) comprising the hockey simulation circuit.

Although the interest in GPS monitoring of cricket is growing, the reliability and validity of this methodology have not yet been established. Cricket is characterized by long periods of low-intensity activity interspersed with short bursts of high-intensity activity.[28] The patterns of the movement are presumably influenced by both the positional requirements and versions of the game. Fast bowlers appear to perform a large number of longer high-intensity efforts compared with other players.[26] In comparison, wicketkeepers appear to have a higher proportion of moderate-intensity activity (jogging) with very few high-intensity bursts.[26] In terms of the different versions of the game: Twenty/20 cricket (T20) is the shortest form of the game and presumably more intensive than both One Day International (ODI) and First Class cricket. Therefore, it is prudent to assess the validity and reliability of GPS measurements over sport-specific distances and locomotion patterns to determine the measurement error. If the measurement error is less than the within-player variability in movement patterns from game to game, then coaches and practitioners can confidently use the GPS measurements to estimate game distances and player movement velocities. An understanding of the game-to-game variation in individual distances and velocities to distinguish between heavy and light game load is necessary for prescription of individualized training. From our pilot data, fast bowlers have within-player game-to-game variability of ~20% in distances and velocities. The aim of this study was to determine the reliability and validity of GPS monitoring for quantifying the movement patterns of cricket. A secondary aim was to compare the reliability and validity of the three different GPS units (ranging from 1 to 5 Hz).

Methods

Experimental Design

The viability of GPS monitoring for cricket applications was evaluated by separately investigating the validity, reliability, and practicality of commercially available GPS units. The same participant (male, aged 32 y) participated in all of the measurement trials to eliminate between-subject variability in estimates of reliability and validity.

GPS Units

Three different types of GPS units were used in this investigation: SPI-10 and SPI–Pro (GPSports, Canberra, Australia) and MinimaxX (Catapult, Melbourne, Australia). The MinimaxX and SPI-Pro units operate with a 5-Hz GPS signal, whereas the SPI-10 uses only a 1-Hz GPS signal. Two individual MinimaxX units (MinimaxX-A and MinimaxX-B) and two individual SPI-Pro units (SPI-Pro-A and SPI-Pro-B) were used to determine the magnitude of between-unit variation.

Both brands of GPS unit are currently used in elite Australian and New Zealand cricket to assess distances covered in various velocity bands (detailed below). The GPS unit under evaluation was positioned via an elasticized shoulder harness to sit between the scapulae of the participant at the base of the cervical spine. Two units separated horizontally by 10 cm were worn simultaneously in each trial.

Distance Trials

The estimated distance covered in different movement categories (walking, jogging, running, and striding) by Academy fast bowlers[26] were used to validate each GPS unit against the criterion distance covered on an internationally certified synthetic 400-m athletics running track. These velocity zones have been used in Australian cricket for the last 2 y. The criterion distance and velocity band for each movement category were as follows: walking (up to 2 $m \cdot s^{-1}$) 8800 m, jogging (2 to 3.5 $m \cdot s^{-1}$) 2400 m, running (3.5 to 4 $m \cdot s^{-1}$) 1200 m, and striding (4 to 5 $m \cdot s^{-1}$) 600 m. Twenty trials were conducted for each unit for each distance. Pacing feedback was given every 200 m to ensure adherence to the specified locomotion speed, and timing was conducted with a manual stopwatch. Because 400-m athletics tracks are measured 30 cm from the inner edge of lane 1, the participant was instructed to try to maintain this radius (with the center of his shoulders) around the track.

Sprint Trials

The two MinimaxX units and the two SPI-Pro units were used in 20 trials with sprints conducted from a standing start over 20, 30, and 40 m. Electronic timing gates were used to obtain a criterion sprint time accurate to 0.01 s. The estimated sprint distance was determined with Logan plus v4.0 (Catapult, Melbourne, Australia) or Team AMS v2.0 (GPSports, Canberra, Australia) software for each trial. The start time was determined by the first increase above zero on the velocity trace and then, using each associated sprint time (from timing gates), the associated distance was determined. It was not possible to test the SPI-10 in the sprint trials given the limitations of a 1-Hz (1 cycle per second) sampling rate for sprints lasting ~3 s.

A cricket-specific run-a-three test was also used to evaluate the ability of the GPS units to monitor sprinting activities. Batsmen often complete multiple runs at a time in a game involving changing direction 180° at each turn. While the length of the pitch between crease lines is 17.68 m, a batsman will use the bat to touch over the crease line so they generally run a shorter distance. The run-a-three test involved a set of electronic light gates positioned on both the crease marks and one camera placed perpendicular to each crease mark to record where the batsman turned. A 1-m calibration mark was made from the crease mark to calibrate the distance for software analysis (SiliconCoach, New Zealand). The horizontal displacement of the MinimaxX or SPI-Pro units' position from the crease lines was determined. Twenty trials of the run-a-three test were used to validate each MinimaxX or SPI-Pro unit. The criterion distance covered in each particular run-a-three test trial was determined using the video recordings, and these were compared with the distances obtained from the GPS units.

Between-Unit Variation and Time of Day

To assess the variation between different GPS units, a custom-designed platform was attached to a calibrated trundle wheel (refer to Figure 1). Nine MinimaxX units were placed in a vertical position on the platform. The trundle wheel was then wheeled over 1200 m at a walking speed around an athletics track with three trials performed at 4:00 PM, and a further three trials at 9:30 AM on the next morning. This method permitted the assessment of the effect of time of day on reliability and validity.

Statistical Analyses

Validity was estimated by subtracting the estimated distance traveled for each trial from the associated criterion distance. For each locomotion pattern, the standard deviation of the percentage errors for each unit gave the standard error of the estimate (SEE). Precision of estimation was indicated with 90% confidence limits. Reliability was estimated using the typical error (TE) expressed as the coefficient of variation (with 90% confidence limits). Bias was determined by subtracting the criterion distance from the GPS estimated distance, and then dividing the difference score by the criterion distance. The data were tested for heteroscedasticity by

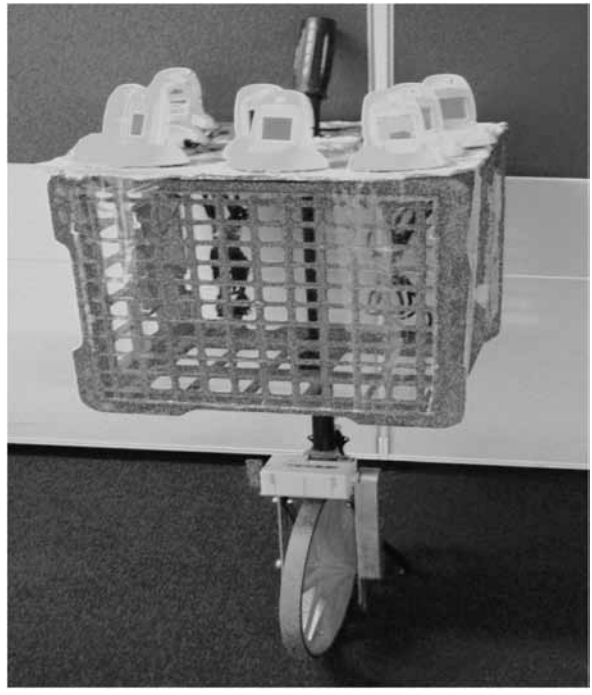


Figure 1 — Trundle wheel with milk crate platform. Nine GPS units are positioned in cradles on this platform for simultaneous recording of distance traveled.

plotting a figure of absolute difference against the mean and computing the correlation.[29]

Results

Validity

Validity was assessed over a range of distances and locomotion patterns specific to cricket. Using all distances, the Pearson correlation (r) for the distance around the track and the estimated distance from the GPS units was 0.99. The data displayed a trivial amount of heteroscedasticity $R^2 = .03$, indicating that as the size of the measurement increases there are only trivial measurement differences. The degree of validity varied as a function of distance and intensity of the locomotion pattern (Table 1). The validity of the SPI-10 unit during walking to striding locomotion patterns ranged from 0.5% to 2.1%. Estimation of running had more than twice the error of walking, jogging, or striding (Table 1). The mean SEE of the SPI-Pro units for the same locomotion patterns varied between 0.4% to 3.7%, with estimation of jogging having the greatest error. Larger errors were evident in sprinting short distances (20–40 m) where the SEE for the SPI-Pro units ranged between 3 and 11%. Similarly, the SEE for the MinimaxX units varied between 2 and 4% for walking to striding and 5 and 24% for sprinting. The validity of the MinimaxX units improved the greater the sprint distance in the range of 20 to 40 m.

Reliability

Similar to validity, the reliability of GPS estimation of locomotion patterns was better for longer distances (Table 2). The SPI-10 had good reliability with the TE <2% over the different distances walking to striding, while the SPI-Pro was <4%. The MinimaxX units displayed similar reliability over the same locomotion patterns with TE <4%. The reliability of the SPI-Pro units during sprinting ranged from 2% to 13%, with the shorter sprints (20 m) tending to be less reliable compared with the longer (40 m and run-a-three) sprints. The reliability of the MinimaxX units during sprinting ranged from 4% to 43%, again with estimation of the shorter sprints (20 m) less reliable than the longer (40 m and run-a-three) efforts.

Bias

The SPI-10 unit underestimated the criterion distance of walking through to striding by 1% to 3% (Table 3). Similarly, the SPI-Pro units underestimated the criterion distance of walking through to striding by 1% to 4%. In sprinting, the SPI-Pro units substantially underestimated the sprinting distances by between ~6% to 20%. In contrast, the MinimaxX units overestimated the criterion distance of walking to striding by up to 3%. However, the MinimaxX units substantially underestimated the sprinting distances by between ~20 and 40%.

Table 1 Standard error of the estimate of commercially available GPS units in cricket-specific movement patterns and distances (percent standard error of the mean ± 90% confidence limits)

	MinimaxX-A	MinimaxX-B	SPI-10	SPI-Pro-A	SPI-Pro-B
Walking 8800 m (up to 2m/s)	3.8 ± 1.4	2.0 ± 0.8	0.6 ± 0.2	1.0 ± 0.4	0.5 ± 0.2
Jogging 2400 m (2–3.5 m/s)	2.6 ± 1.0	1.8 ± 0.7	0.5 ± 0.2	3.7 ± 1.4	1.5 ± 0.5
Running 1200 m (3.5–4 m/s)	2.8 ± 1.0	3.0 ± 1.1	2.1 ± 0.8	2.4 ± 0.9	0.7 ± 0.2
Striding 600 m (4–5 m/s)	1.7 ± 0.6	1.8 ± 0.7	0.8 ± 0.3	3.0 ± 1.1	0.4 ± 0.1
Sprinting 20 m (+ 5 m/s)	15.2 ± 5.6	23.8 ± 8.8	—	5.5 ± 2.0	10.5 ± 3.9
Sprinting 30 m (+ 5 m/s)	14.4 ± 5.3	19.7 ± 7.2	—	4.2 ± 1.5	7.6 ± 2.8
Sprinting 40 m (+ 5 m/s)	14.9 ± 5.5	16.1 ± 5.9	—	2.9 ± 1.1	7.7 ± 2.8
Sprinting Run-a-Three (+ 5 m/s)	12.7 ± 4.7	5.3 ± 2.0	—	6.7 ± 2.5	2.6 ± 1.0

Table 2 Reliability of commercially available GPS monitoring (coefficient of variability with 90% confidence limits) of cricket-specific movement patterns and distances

	MinimaxX-A	MinimaxX-B	SPI-10	SPI-Pro-A	SPI-Pro-B
Walking 8800 m (up to 2m/s)	2.6 (2.1–3.6)	1.4 (1.1–2.0)	0.4 (0.3–0.6)	0.7 (0.6–1.0)	0.3 (0.3–0.5)
Jogging 2400 m (2–3.5 m/s)	1.8 (1.5–2.5)	1.3 (1.0–1.7)	0.4 (0.3–0.5)	2.9 (2.3–4.0)	1.1 (0.9–1.5)
Running 1200 m (3.5–4 m/s)	2.0 (1.6–2.7)	2.0 (1.6–2.8)	1.5 (1.2–2.1)	1.8 (1.4–2.5)	0.5 (0.4–0.7)
Striding 600 m (4–5 m/s)	1.2 (1.0–1.7)	1.3 (1.0–1.8)	0.5 (0.4–0.7)	2.3 (1.8–3.1)	0.3 (0.2–0.4)
Sprinting 20 m (+ 5 m/s)	19.7 (15.3–27.9)	30.0 (23.2–43.3)	—	4.8 (3.8–6.6)	9.3 (7.3–13.0)
Sprinting 30 m (+ 5 m/s)	15.8 (12.4–22.3)	21.3 (16.5–30.3)	—	3.4 (2.7–4.7)	6.3 (5.0–8.7)
Sprinting 40 m (+ 5 m/s)	16.1 (12.5–22.6)	17.1 (13.4–24.2)	—	2.3 (1.8–3.1)	5.8 (4.6–8.1)
Sprinting Run-a-Three (+ 5 m/s)	13.6 (10.7–19.1)	5.3 (4.2–7.3)	—	6.3 (5.0–8.7)	2.0 (1.6–2.8)

Table 3 Percent bias (± 90% confidence limits) of GPS measured distances from criterion distances

	MinimaxX-A	MinimaxX-B	SPI-10	SPI-Pro-A	SPI-Pro-B
Walking 8800 m (up to 2m/s)	2.1 ± 1.4	3.2 ± 0.8	−0.8 ± 0.2	−1.1 ± 0.4	−0.8 ± 0.2
Jogging 2400 m (2–3.5 m/s)	0.3 ± 1.0	0.8 ± 0.7	−0.9 ± 0.2	−2.8 ± 1.4	−2.7 ± 0.5
Running 1200 m (3.5–4 m/s)	0.4 ± 1.0	2.6 ± 1.1	−1.0 ± 0.8	−3.8 ± 0.9	−1.2 ± 0.2
Striding 600 m (4–5 m/s)	0.3 ± 0.6	0.0 ± 0.7	−1.7 ± 0.3	−2.7 ± 1.1	−1.0 ± 0.1
Sprinting 20 m (+ 5 m/s)	−37.3 ± 5.6	−24.3 ± 8.8		−15.3 ± 2.0	−13.6 ± 3.9
Sprinting 30 m (+ 5 m/s)	−27.4 ± 5.3	−20.4 ± 7.2		−10.3 ± 1.5	−11.5 ± 2.8
Sprinting 40 m (+ 5 m/s)	−24.1 ± 5.5	−19.5 ± 5.9		−7.7 ± 1.1	−7.4 ± 2.8
Sprinting Run-a-Three (+ 5 m/s)	−28.9 ± 4.7	−28.1 ± 2.0		−20.0 ± 2.5	−6.1 ± 1.0

Interunit Variability and Time-of-Day Effects

There were minimal differences in validity and reliability measures calculated from MinimaxX GPS data collected in the morning compared with the afternoon. The SEE was 1.7 ± 0.5 and 1.8 ± 0.6 (mean ± 90% confidence limits) and the TE was 1.3 (1.0 to 1.8) and 1.5 (1.2 to 2.0), respectively, for morning and afternoon data. Movement data collected in the morning displayed an underestimation bias of 1%, whereas in the afternoon there was an overestimation bias of 1% (Figure 2).

Discussion

With rapid commercial advancements (and increased commercial competition) in GPS microtechnology, it is important to ensure that the validity, reliability, and practicality to athletic training also improves from the current state. Effective evaluation of the movement patterns and physical demands of cricket can benefit the importance of the prescription of fitness and condition programs. The SEE (validity) of distance for walking to striding ranged from 0.4% to 3.8%, and the estimate of reliability ranged from 0.3% to 2.9%. Even with the same type of GPS unit simultaneously receiving the same satellite signals, there were discernable differences in the estimated distances. A major finding of this investigation was the shortcomings in confidently measuring short sprint efforts. The typical errors

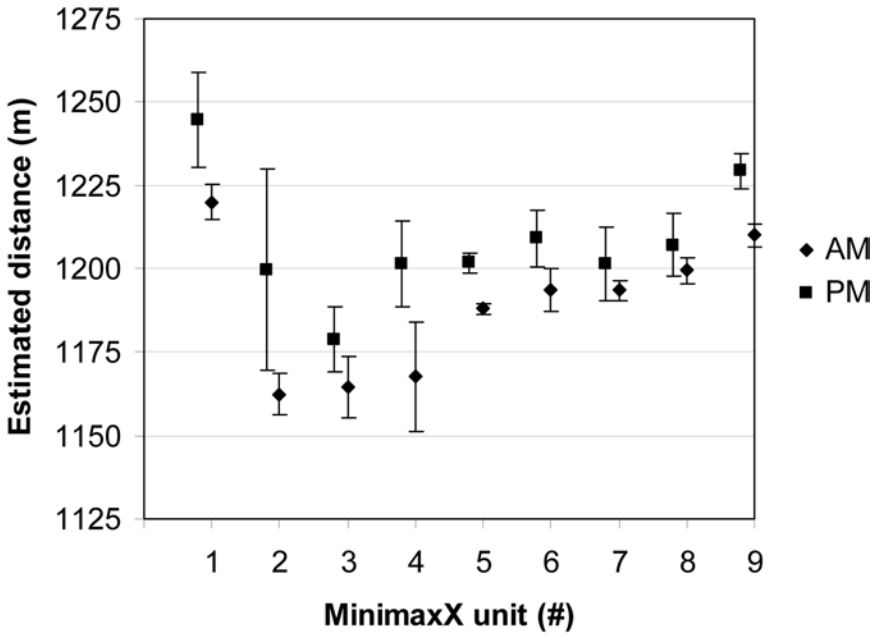


Figure 2 — Interunit variation in estimated distance (mean ± 90% confidence limits) from 1200-m walks with nine GPS units. The three morning trials were conducted at 9:30 AM and three afternoon trials at 4 PM.

of validity and reliability of estimating sprint distances over 20 to 40 m ranged from 3% to 40%. The MinimaxX and SPI-Pro units consistently underestimated short sprint distances. The magnitude of errors associated with particular GPS outputs should be clearly understood by conditioning coaches in monitoring cricket workloads and prescribing training. In particular, conditioning coaches should be aware of the likely underreporting of high-intensity activity and the overreporting of low-intensity activity.

There are obvious differences in outputs between different brands of GPS units, even though the GPS receivers are receiving the same signals from the same satellites. These errors are most likely attributable to variations in the calculation of the receiver position from triangulation algorithms, or the Kalman (exclusion criteria) formula used to determine the most logical position. Errors can also occur in the smoothing techniques used by the software to exclude erroneous data. The degree of smoothing inherent in the analysis will affect the accuracy of the estimated distance or velocity measurements. Therefore, where possible, the same type of unit should be used when making comparisons between athletes or with repeated monitoring on the same athlete (or player) over time.

The validity of the GPS units measured here appears acceptable for longer distances at the slower velocities of locomotion (up to striding) with values of less than 5% fulfilling the criteria used by Duffield and Drinkwater.[14] The MinimaxX units overestimated (by 0% to 3%), whereas the SPI-Pro and SPI-10 units underestimated (up to 4%) these distances. However, caution should be exercised when interpreting short high-intensity efforts by contemporary commercially available GPS units, as validity of sprinting distances ranged up to 24% with an underestimation bias up to 37%. The type of GPS unit used must be accounted for as this will determine the bias it expresses over different locomotion patterns. Furthermore, results from different GPS units should not be used interchangeably when analyzing high-intensity running.[25]

Typical errors of ~2% with lower intensity activity (<4 $m \cdot s^{-1}$) found in the current study are less than half the error reported in a preliminary study[25] that evaluated three different models (SPI-10, SPI Elite, and WiSPI) of GPS units (GPSports, Canberra, Australia). The typical error of estimating very high intensity running (>5.5 $m \cdot s^{-1}$) in Coutts and Duffield's study[25] ranged from 12% to 30%, which is in agreement with our findings. Our data supports their finding of reduced reliability with increased movement velocities. It is possible that because the number of GPS signals is lower during shorter sprints, the distance of these sprints is underestimated and had reduced reliability. A report by the manufacturers of the MinimaxX shows that the MinimaxX GPS unit has a typical error of 0.8% for the criterion distance around a 400-m track.[30] Interestingly, this report indicated improved accuracy during jogging and running compared with walking (3×3 laps around a small 10- $\times$ 10-m square), and concluded that the MinimaxX GPS accuracy typically improves at higher speeds.[30] Our data does not support this conclusion and further refinement of this technology is required before coaches and scientists can be confident about the accuracy of GPS output to quantify short sprints in team sports.

One study reported validity results for measured distance at lower intensity activity far tighter than our current results (typical errors of less than ~2%). This study[27] investigated variable movement speeds around a 6.8-km painted hockey-

specific circuit (1-Hz GPSports Spi Elite unit). The 7 km·h^{-1} average movement speed indicates an overall intensity of walking and with only nine trials of the complete circuit (only one unit used) the authors reported a TE of 0.1%. It would be interesting to see if this TE increased with a greater number of trials and with more regular high-intensity efforts.

Cricket conditioning coaches currently use GPS microtechnology to track patterns of movements both in a game and between-game variation to modify the type, duration, and intensity of conditioning sessions.[26] The reliability of estimating longer distances is acceptable for game and training applications. However, the underestimation bias displayed with the GPS units studied here during sprinting may mean that total game sprint distance is underreported, whereas the total game distance may be overreported when using MinimaxX units. The noise of up to 30% in the measurements of cricket specific-sprinting distances is too large for identifying the smaller within-player game-to-game variability of 20% established with our pilot game data. Conditioning coaches should focus on game-to-game variations in total distance covered rather than the sprinting workload when prescribing and evaluating interval training drills.

In a comparison study of GPS technology (SPI-10) to computer-based tracking software (Trakperformance), Edgecomb and Norton[20] concluded that computer-based tracking was as accurate as GPS technology. Their reliability results (TEM of 5.5%) for movements up to a running intensity were more than twice the value found in our present study for the equivalent SPI-10 GPS unit. Improvements made in the intervening period to the GPS technology (updates in firmware or software) may be the reason for these improved results. With the increased reliability and the practical convenience of GPS monitoring, it appears that notational analysis and manually controlled computer tracking software will soon be superseded in sports allowing GPS technology. However, notational analysis and manually controlled computer tracking software is often the only option for indoor sports, certain contact sports (safety of landing on the unit), and sports that impose restrictions on using GPS technology in competition.

Practical Applications

The estimations of distance with GPS were remarkably consistent between the morning and afternoon. This finding confirms those of MacLeod et al,[27] who also reported that different configurations of satellites at different times of the day did not substantially affect the GPS output. Our results indicate that temporal longitudinal comparison of GPS data can be made with confidence. However, it is noticeable to any frequent user of GPS technology that satellite reception can vary with location. Therefore, we advise practitioners to routinely check indicators of signal quality and number of satellites being used when interpreting GPS data. It is also advisable for coaches to check their own units to establish individual unit bias and, if possible, use the same unit for a particular player (if possible, do not use units interchangeably[25]).

In conclusion**,** in comparison with other workload-monitoring techniques, GPS athlete tracking technology is practically superior. This technology can provide acceptable validity and reliability for estimating longer distances of walking to striding intensity. However, there are shortcomings in the ability of the technol-

ogy to reliably quantify shorter cricket-specific sprinting distances. Further improvements are required for detailed analysis of high-intensity efforts in the disciplines of batting, bowling, and fielding.

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Chapter 5

Analysis of Game Demands

Study 4: Variability in movement patterns during One Day Internationals by a cricket fast bowler.

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CASE STUDY

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Variability in Movement Patterns During One Day Internationals by a Cricket Fast Bowler

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Purpose: The time-motion characteristics and the within-athlete variability in movement patterns were quantified for the same male fast bowler playing One Day International (ODI) cricket matches (n = 12). ***Methods:*** A number of different time motion characteristics were monitored using a portable 5-Hz global positioning system (GPS) unit (Catapult, Melbourne, Australia). ***Results:*** The bowler's mean workload per ODI was 8 ± 2 overs (mean ± SD). He covered a total distance of 15.9 ± 2.5 km per game; 12 ± 3% or 1.9 ± 0.2 km was striding (0.8 ± 0.2 km) or sprinting (1.1 ± 0.2 km), whereas 10.9 ± 2.1 km was spent walking. One high-intensity (running, striding, or sprinting) repetition (HIR) occurred every 68 ± 12 s, and the average duration of a HI effort was 2.7 ± 0.1 s. The player also completed 66 ± 11 sprints per game; mean sprint distance was 18 ± 3 m and maximum sprinting speed 8.3 ± 0.9 $m \cdot s^{-1}$. ***Conclusions:*** The movement patterns of this fast bowler were a combination of highly intermittent activities of variable intensity on the base of ~16 km per game. This information provides insight for conditioning coaches to determine the physical demands and to adapt the training and recovery processes of ODI fast bowlers.

Keywords: fast bowling, GPS, workload, time-motion

Quantification of movement patterns through time-motion analysis studies is important for conditioning coaches to develop sport-specific conditioning programs and to tailor recovery periods based on quantified game demands. Recent studies have published time-motion characteristics of cover-point fielders[1] and batsmen[2] during first-class and international cricket, respectively. These studies used video footage and manual notational analysis on a single player at a time. This approach is too time consuming for routine use in a practical setting to obtain

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movement data for modifying an individual athletes' training. The advent of GPS devices to automatically monitor movement patterns is an active area of research across many sports. No previous study has examined the movement patterns in cricket using GPS technology. The aim of this case study was to describe the movement patterns, and degree of variability, in a fast bowler during One Day International (ODI) cricket.

Methods

Time-motion characteristics of an Australian fast bowler were monitored using a portable 5-Hz global positioning system (GPS) unit (Catapult, Melbourne, Australia) during 12 ODI games, including six vs India, three vs Bangladesh, two vs Sri Lanka, and one vs New Zealand. The GPS unit was positioned via an elasticized shoulder harness to sit between the scapulae of the bowler at the base of the cervical spine (Figure 1). The GPS unit was activated and GPS satellite lock was established for at least 15 min before the player taking the field as per the manufacturer's recommendations. After each session, the recorded information was downloaded using Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) for analysis. Total distance (km), distance traveled walking (movement speed, 0 to 2 $m \cdot s^{-1}$), jogging (2 to 3.5 $m \cdot s^{-1}$), running (3.5 to 4 $m \cdot s^{-1}$), striding (4 to 5 $m \cdot s^{-1}$) and sprinting (5+ $m \cdot s^{-1}$), number of sprints, maximum speed ($m \cdot s^{-1}$), maximum sprint distance (m), number of efforts greater than jogging, and the recovery time between high-intensity efforts (running, striding, sprinting) were the time-motion characteristics assessed. The data from different game durations (184 ± 41 min) was scaled to 210 min (time allocated for an ODI innings) to facilitate interpretation and application of the results. The data are presented as mean ± SD. The coefficient of variation (CV) was calculated to represent the within-athlete variability in movement patterns across the ODI games.



Figure 1 — Athlete wearing shoulder harness with portable GPS device.

Results

Table 1 details the movement characteristics obtained from the same bowler during 12 ODI games. Approximately two-thirds of the 15.9 km covered was walking interspersed with short distance, higher intensity sprint efforts (typical sprint distance 18 m). The CV ranged from 1 to 37%, with the time spent walking the least variable, and the distance covered jogging and the maximum sprint distance the two most variable movement characteristics.

Discussion

Time-motion analysis of cricket should provide insightful information on the movement patterns of different players. In cricket, players within the same team experience substantially different workloads, depending on the ground size, length of bowling spells, and their position and role within a particular game. International fast bowlers undertake the greatest amount of work of any cricketing position analyzed. This bowler covered ~16 km in 3.5 h, which is almost twice the workload of cover-point fielders (in first-class cricket), who cover 15.5 km in 6 h.[1] The comparatively higher demands of fast bowling compared with batting are

Table 1 Time-motion variables of an international fast bowler playing One Day International cricket. The movement data in each category is scaled to a game duration of 210 min. SD = standard deviation, CV = coefficient of variation

Workload characteristic	Mean	SD	(%)	CV (%)
Distance				
Walking (0–2.0 m·s^{-1}) (m)	10,914	2,146	69	20
Jogging (2.0–3.5 m·s^{-1}) (m)	2,490	904	16	36
Running (3.5–4 m·s^{-1}) (m)	560	145	4	26
Striding (4.0–5.0 m·s^{-1}) (m)	798	158	5	20
Sprinting (5+ m·s^{-1}) (m)	1,140	246	7	22
Total distance (m)	15,903	2,552	—	16
Time				
Walking & Jogging (s)	12,044	84	96	1
Running, Striding, and Sprinting (s)	525	87	4	17
Sprint				
Number (#)	66	11	—	17
Mean sprint distance (m)	18	3	—	17
Maximum sprint distance (m)	54	20	—	37
Maximum sprinting speed (m·s^{-1})	8.3	0.9	—	11
High-intensity efforts				
Number (#)	191	32	—	17
Mean effort duration (s)	2.7	0.1	—	5
Recovery between (s)	68	12		18

indicated by 4.2% of game time composed of high-intensity activity compared with only 2.8% for ODI century scoring batsmen.[2]

Understanding the game-to-game variability that an individual player exhibits will help determine the amount of physical preparation and recovery that a bowler or player needs. For this individual bowler, the majority (11 of 15) of the workload characteristics analyzed had game-to-game variability of 20% or less. Based on such collected GPS data, conditioning coaches employing GPS monitoring can objectively modify and individualize the periodization of the fitness training of elite cricketers. Future work should quantify the mean values and magnitude of variability in movement patterns for other positions and during other formats of the game (eg, test cricket and twenty20).

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Chapter 5

Analysis of Game Demands

Study 5: Quantifying positional movement patterns in Twenty20 cricket.

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Quantifying positional movement patterns in Twenty20 cricket

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Abstract

The time-motion characteristics of five cricket positions (Batsmen, Fast bowlers, Fielders, Spin bowlers, Wicketkeepers) were quantified during four State Twenty20 (T20) cricket matches. A total of 18 different players were monitored over 30 innings. Several time motion characteristics were quantified using portable 5Hz global positioning system (GPS) units. Descriptive statistics (mean ± SD) were used to describe the data while the effect size statistic was used to determine the magnitude of difference in patterns of movement between positions. T20 cricketers covered between 6.4 - 8.5 km, with 0.1 – 0.7 km of this distance spent sprinting during an 80 min fielding innings. Fast Bowlers covered 8.5 ± 1.5 km; sprinted 42 ± 8 times, mean sprint distance was 17 ± 2m and total sprinting distance was 0.7 ± 0.2 km. Wicketkeepers covered 6.4 ± 0.7 km; sprinted 5 ± 2 times, mean sprint distance was 10 ± 3m and total sprinting distance was 62 ± 44m. While batting (30 min) players covered ~2.5 km; sprinted 12 ± 5 times, mean sprint distance was 14 ± 3m and total sprinting distance was 160 ± 80m. Fast bowlers and fielders have substantially greater physical demands than spin bowlers and wicketkeepers in T20 cricket.

Keywords: GPS, time-motion, bowling, wicketkeeping, fielding, batting.

1. Introduction

Twenty20 (T20), the shortest and fastest version of cricket, is proving to be a popular format in terms of drawing spectators and the most profitable for players, administrators, coaches and owners. With so much money invested in this version of the game, franchise owners, management teams and coaches would be wise to apply successful game tactics, and select players most capable of executing a proven game strategy (Petersen et al, 2008). Investigating the physical requirements of the game and how these vary by position is a key consideration for coaching and conditioning staff. Given this is presumably the most intensive game format; it is likely that T20 requires skill execution under a comparatively higher level of fatigue. Physical fitness potentially impacts on the ability to execute the skills required to implement a particular game strategy (Rampinini et al, 2008). Increased knowledge of the positional game requirements of T20 cricketers will enable conditioning coaches to design more effective individualised training programmes.

In T20 each team faces 20 six-ball overs, with fielding restrictions termed a powerplay (only 2 fielders are allowed outside the 30 yard circle, with another 2 players besides the wicketkeeper in catching positions a maximum of 15 yards from the bat) applying in the first six overs of each innings. The allocated time for each innings is 80 minutes, with specific rules implemented in T20 cricket to increase the speed of the game; dugouts have players closer to the pitch and the new batsman must be ready within 90 seconds (2 minutes in other forms of cricket) after a wicket falls or risk being 'timed out'. There are also financial penalties imposed upon team captains and players for time wasting and slow over rates. Anecdotally, the rules seem effective in speeding up the game as players jog between fielding positions and run to get into position between overs.

Recently, an analysis of team, batting and bowling indicators of performance showed that winning T20 sides captured more wickets in the first and last six overs of an innings (Petersen et al., 2008). In addition, data from the Hawk-Eye™ video-based ball tracking system has been used to compare the bowling styles (ball release speed, pitching line and length) between three different types of matches (Test, 50-over, and T20) and three different types of right arm bowler (fast, medium and off-spin). The authors found that the bowler's styles remained constant despite the batsmen's playing style becoming more aggressive in the shorter the game formats of cricket (Justham et al., 2008). Although these studies highlight actual strategies and tactics of game play they did not describe the player physical demands.

Time-motion studies employing Global Positioning System (GPS) units to automatically monitor player movement patterns are being increasingly used across many sports. Cricket conditioning coaches are increasingly using GPS technology to modify the training of individual players, and broadcasters are beginning to show actual distances covered during different formats of cricket. However there is no published data examining the movement patterns (inter-player total distance covered, number of sprints, and mean sprint distance) of different positions in T20 cricket. The purpose of this study was to quantify the positional movement demands of T20 cricketers. We also sought to quantify the magnitude of differences in movement patterns between fielders and specialist positions (wicketkeeper, fast and spin bowlers).

2. Methods

Time motion characteristics of Australian state-level T20 male cricketers (n=18) were monitored using portable 5Hz global positioning system (GPS) units (Catapult, Melbourne, Australia) during four domestic T20 games (total of 30 innings). The standard error of the estimate (validity) of distance for walking to striding for these GPS units ranged from 0.4 to 3.8%; whereas the estimate of reliability ranged from 0.3 to 2.9%. For sprinting, the typical errors of validity and reliability of estimating distances over 20-40 m ranged from 3 to 40% (Petersen et al, 2009a).

Each player was classified as either: a batsman, fast bowler, fielder, spin bowler or wicketkeeper. Each GPS unit was positioned via an elasticized shoulder harness to sit between the scapulae of the player at the base of the cervical spine. The GPS unit was activated and GPS satellite lock established for at least 15 min prior to the player taking

the field as per the manufacturer's recommendations. After each session the unit was downloaded using Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) for analysis. Total distance (km), distance travelled walking (movement speed 0 – 2 $m.s^{-1}$), jogging (2 – 3.5 $m.s^{-1}$), running (3.5 – 4 $m.s^{-1}$), striding (4 – 5 $m.s^{-1}$) and sprinting (5+ $m.s^{-1}$), number of sprints, maximum speed ($m.s^{-1}$), maximum sprint distance (m), number of efforts more intense than jogging, and the recovery time between high intensity efforts (running, striding, sprinting) were quantified. Descriptive statistics (mean ±SD) were used to characterize the central tendency of the data. To facilitate interpretation and application of the results, the data from different game lengths was scaled to 80 minutes (ICC sanctioned time allocated for a T20 innings) for each fielding innings, while batting files were scaled to a 30 min innings. Batting innings shorter than 15 min were excluded from analysis.

The approach of magnitude-based inferences to analyse the time-motion characteristics by position was adopted (Batterham and Hopkins, 2006). The effect size statistic was generated to assess the magnitude of difference between the generic fielder position and the three specialist positions (wicketkeeper, fast and spin bowler). The criteria for interpreting effect size were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, and > 2.0 very large (Hopkins, 2004).

3. Results

The movement characteristics obtained from the five positions during four T20 games are detailed in Table 1. T20 cricketers during an 80 min fielding innings covered 6.4 – 8.5 km, with 0.1 – 0.7 km of this distance spent at sprinting velocities. Sprinting accounted for 9, 7, 7, 2 and 1 % of the total distance covered for fast bowling, batting, fielding, spin bowling and wicketkeeping respectively. In comparison, walking accounted for approximately 66% of the total distance covered by spin bowlers, wicketkeepers and the batsmen, but only ~50 % of the total distance covered by fielders and fast bowlers.

The magnitude of difference in movement patterns between fielders and specialist positions (fast bowlers, spin bowlers and wicketkeepers) is also displayed in Table 1. Fast bowlers had 11 more sprints (ES = 0.66), 33 more high intensity efforts (ES = 0.60) and 13 seconds less recovery time between high intensity efforts (ES = 0.60) than fielders. While magnitude comparisons for batting are not displayed in Table 1; compared to fielders batsmen had slightly longer recovery time between high intensity efforts (53 vs. 45 s: ES = 0.37). In contrast, compared to fast bowlers batsmen had moderately greater recovery time between high intensity efforts (53 vs. 32 s: ES = 1.05). Spin bowlers had only one-third of the number of sprints completed by fielders and half as many high intensity efforts. Consequently, spin bowlers only covered a third of the total distance running and sprinting covered by fielders. However, because spin bowlers covered ~45% more distance walking than fielders, they enjoyed twice as much recovery time between high intensity efforts (106 vs. 45 s: ES = 2.4).

Table 1. Time-motion variables (mean ± SD) of state T20 cricketers. The movement data in each position is scaled to a game duration of 80 min (except batting = 30min).

Workload characteristic	Batsmen (n=6)	Fast bowlers (n= 4)	Fielders (n= 14)	Spin bowlers (n= 3)	Wicketkeepers (n= 3)
Distance					
Walking (0 – 2.0 m.s^{-1}) (m)	1644 ± 507	4288 ± 884	4381 ± 968	6336 ± 938[d]	4670 ± 545[a]
Jogging (2.0 – 3.5 m.s^{-1}) (m)	395 ± 114	2195 ± 624[a]	2042 ± 481	1627 ± 543[b]	1301 ± 155[c]
Running (3.5 – 4 m.s^{-1}) (m)	80 ± 34	559 ± 184[a]	502 ± 208	215 ± 136[c]	222 ± 55[c]
Striding (4.0 – 5.0 m.s^{-1}) (m)	153 ± 91	725 ± 322	663 ± 421	240 ± 224[b]	178 ± 33[c]
Sprinting (5+ m.s^{-1}) (m)	161 ± 83	723 ± 168[a]	554 ± 353	154 ± 144[c]	62 ± 44[c]
Total distance (m)	2433 ± 450	8489 ± 1493[a]	8141 ± 1308	8537 ± 1568[a]	6433 ± 760[c]
Time					
Walking & Jogging (s)	1706 ± 47	4366 ± 122	4350 ± 249	4560 ± 281[b]	4686 ± 21[c]
Running, Striding & Sprinting (s)	81 ± 43	431 ± 123[a]	367 ± 195	134 ± 104[c]	111 ± 23[c]
Sprint					
Number (#)	12 ± 5	42 ± 8[b]	31 ± 18	10 ± 8[c]	5 ± 2[c]
Mean sprint distance (m)	14 ± 2	17 ± 2	17 ± 4	15 ± 5[a]	10 ± 3[c]
Maximum sprint distance (m)	34 ± 12	51 ± 20	54 ± 23	38 ± 18[b]	20 ± 11[c]
Maximum sprinting speed (m.s^{-1})	7.5 ± 1.0	9.1 ± 0.6[a]	8.6 ± 1.1	8.9 ± 2.0[a]	6.5 ± 0.7[c]
High intensity efforts					
Number (#)	38 ± 17	163 ± 44[b]	130 ± 57	56 ± 35[c]	50 ± 12[c]
Mean effort duration (s)	2.2 ± 0.2	2.6 ± 0.1[a]	2.8 ± 0.5	2.2 ± 0.4[c]	2.2 ± 0.1[c]
Recovery between (s)	53 ± 24	32 ± 10[b]	45 ± 21	106 ± 49[d]	101 ± 28[d]

[a] Small, [b] moderate, [c] large and [d] very large magnitude of difference of time-motion variables of specialist fielding positions (Fast bowlers, spin bowlers and wicketkeeper) from the generic fielder position.

The wicketkeepers covered substantially less distance in jogging, running, striding and sprinting, than fielders. Notably, fielders covered ~8 times greater distance sprinting as wicketkeepers. Yet, wicketkeepers covered slightly more distance than fielders (290 m; 6% more) at walking intensity. Like the spin bowlers, wicketkeepers enjoyed twice the recovery time from high intensity efforts as fielders (101 vs. 45 s: ES = 3.0).

4. Discussion

Cricket conditioning coaches often work with players in their squad who are involved in all three formats of the game. This study provides descriptive data of T20 state level cricket and shows that fast bowlers have the highest, and wicketkeepers the lowest, workloads. T20 cricketers in the field (excluding wicketkeepers) typically covered between covered between 8.1 - 8.5 km during an 80 min fielding innings, with 0.2 – 0.7 km of this distance spent at sprinting velocities. In comparison wicketkeepers covered 6.4 km, with only 60 m spent at sprinting intensity. Players batting for 30 min covered 2.5 km with 160 m run at sprinting intensity. Coaches must reconcile differences in physical demands and movement patterns between game formats to formulate game and position-specific training plans.

Published data is starting to emerge defining the workload characteristics from different formats of cricket. Fielders in English county (first-class) cricket covered 15.5 km (2.6 $km.hr^{-1}$) in a day (Rudkin and O'Donoghue, 2008). In comparison T20 fielders covered almost 2.5 times more distance per hour (6.1 $km.hr^{-1}$). While a time-motion study (conducted via video recordings) of international batsmen scoring centuries did not estimate distance covered, 98.6% (Test) and 97.7% (One Day) of the batsmen's time was spent stationary, walking and jogging (Duffield and Drinkwater, 2008). In comparison, for the same movement patterns, T20 batsmen spent only 95.5% of their time at these lower intensities. Therefore, when compared to the longer formats of cricket, a greater proportion of time batting in T20 cricket is spent at higher intensities. Similarly, a case study conducted over 12 games reported an international One Day fast bowler covered ~16 km in 3.5 hours with 1.1 km (7%) at sprinting intensity (Petersen, et al., 2009b). In comparison, T20 fast bowlers covered 0.7 km (8.5%) of their total distance (8.5 km) at sprinting intensities. While a T20 innings is only 38% of the time taken for a One Day innings, fast bowlers covered 53% of the total distance and 63% of the sprinting distance reported for the international One Day fast bowler. Studies with larger sample sizes are required to confirm these preliminary estimates. It is also likely that the physical workload of international T20 matches would be greater than state T20 matches. Nevertheless, it appears that the physical demands of T20 cricket are likely to be more intensive than One Day and Test cricket.

When designing position-specific training programmes coaches should consider the positional differences identified in Table 1. Fast bowlers undertake the greatest workload at the highest intensity and have 13 s less recovery time between high intensity efforts as fielders. Therefore coaches should (where possible) seek fielding placements for their fast bowlers to the enhance recovery between high intensity efforts and limit the potential of fielding tasks impacting on their bowling performance. In comparison, spin bowlers are able to undertake their bowling with twice the recovery

time from high intensity efforts as fielders. Future work classifying movement demands by actual fielding position should identify the most advantageous fielding placement for fast bowlers. However the specialist skills required for some positions (slips catching) needs to be taken into account when assigning positions in the field.

In cricket, players within the same team experience substantially different workloads, depending on among other factors their position, involvement and role within a game (Petersen et al., 2009b). Understanding both the positional and game format differences in workload will help conditioning coaches to determine the amount of physical preparation and recovery that players need. Coaches that don't have access to time-motion information on their players must rely on published or established values to estimate the physical loading on players. Managing the workload and recovery of players is becoming more important and increasingly complex with the increased opportunities for first-class players to play in a number of different professional leagues during the season. Future work should further quantify the positional workload in T20 with a greater sample size, and determine the magnitude of game-to-game variability in movement patterns for batsman, bowlers and fielders.

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Chapter 5

Analysis of Game Demands

Study 6: Movement patterns in cricket vary by both position and game format.

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Movement patterns in cricket vary by both position and game format

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Abstract
We compared the movement patterns of cricketers in different playing positions across three formats of cricket (Twenty20, One Day, multi-day matches). Cricket Australia Centre of Excellence cricketers ($n = 42$) from five positions (batting, fast bowling, spin bowling, wicketkeeping, and fielding) had their movement patterns (walk, jog, run, stride, and sprint) quantified by global positioning system (GPS) technology over two seasons. Marked differences in movement patterns were evident between positions and game formats, with fast bowlers undertaking the greatest workload of any position in cricket. Fast bowlers sprinted twice as often, covered over three times the distance sprinting, with much smaller work-to-recovery ratios than other positions. Fast bowlers during multi-day matches covered 22.6 ± 4.0 km (mean ± *s*) total distance in a day (1.4 ± 0.9 km in sprinting). In comparison, wicketkeepers rarely sprinted, despite still covering a daily total distance of 16.6 ± 2.1 km. Overall, One Day and Twenty20 cricket required ~50 to 100% more sprinting per hour than multi-day matches. However, multi-day cricket's longer duration resulted in 16–130% more sprinting per day. In summary, the shorter formats (Twenty20 and One Day) are more intensive per unit of time, but multi-day cricket has a greater overall physical load.

Keywords: *Batting, bowling, fielding, limited overs, Twenty20*

Introduction

Contemporary conditioning programmes are based on detailed knowledge of a sport's movement patterns and physiological demands. Many sports, including Australian football (Dawson et al., 2004), basketball (Bishop & Wright, 2006), field-hockey (Spencer et al., 2004), rugby (Deutsch, Kearney, & Rehrer, 2007; Duthie, Pyne, & Hooper, 2005), football (Bangsbo Mohr, & Krustrup, 2006), Gaelic football (King & O'Donoghue, 2003), and water polo (D'Auria & Gabbett, 2008), have been studied using time–motion analysis to describe their physical demands. Cricket is unique in that three different game formats, namely Twenty20, One Day, and multiple-day (Test and first-class) cricket, are played by elite players. To date, there are no comprehensive cricket time–motion studies accounting for both positional differences and game format.

Two preliminary time–motion studies have been conducted separately on first-class (county) fielding and international (Test and One Day) batting. Rudkin and O'Donoghue (2008) used real-time computerized time–motion analysis to observe 27 infielders for 10 overs. Extrapolating the data using prior electronically timed 15-m speed trials, the authors estimated that infielders covered ~15.5 km in a day (3 × 2 h sessions). Duffield and Drinkwater (2008) used video recordings to compare century-scoring batsmen from One Day and Test cricket. The authors reported that similar proportions of time (One Day: 94%; Test: 96%) were spent in low-intensity (standing and walking) activity. However, because a Test match century took 37% longer to complete than a One Day International century, there were much longer recovery bouts between high-intensity efforts in Test cricket. While this study categorized movement descriptors into component parts (standing, walking, jogging, striding, sprinting, playing a shot, and lateral motion), the authors only reported temporal data with no estimates of the true distances covered.

Based on game descriptors, Noakes and Durandt (2000) described how in 1955 Fletcher calculated that Test batsmen covered less than 520 $m \cdot h^{-1}$

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(~3.1 km in a day) and Test players had an average energy expenditure (650 $kJ \cdot h^{-1}$) slightly above that achieved when standing. Perhaps unfairly, Fletcher included time spent sitting watching the game in these calculations, therefore under-representing playing energy expenditure. Recent simulations of One Day cricket (Christie, Todd, & King, 2008) have estimated much higher energy demands of batsmen (i.e. 2536 $kJ \cdot h^{-1}$). Moreover, in their analysis of first-class fielding in the United Kingdom, Rudkin and O'Donoghue (2008) concluded that cricket is physically undemanding. Fletcher's work may have reflected the game and fielding demands in the 1950s, while Rudkin and O'Donoghue's work characterizes the current first-class fielding requirements in the United Kingdom. Together, these assertions reinforce the historical and contemporary perception that cricket is a physically undemanding sport. However, it is also possible, as shown by Christie et al. (2008), that these findings have underestimated the physiological demands of cricket.

Traditionally, time–motion studies have been conducted in real-time with pen, paper, and stopwatch/computer (notational) or post-game processing using video recordings with or without customized computer analysis (digitizing). Today, global positioning system (GPS) player tracking technology provides a more convenient, less time-consuming, and practically superior method for data collection (MacLeod, Morris, Nevill, & Sunderland, 2009; Townshend, Worringham, & Stewart, 2008). Data collected in time–motion studies help to develop knowledge of the positional differences in workload with different game formats. This information allows conditioning coaches to prescribe more game-specific training programmes. Therefore, the aim of this study was to quantify the movement patterns undertaken by players in different positions and formats of cricket.

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Methods

Participants

Forty-two Cricket Australia Centre of Excellence male cricketers (age 22.1 ± 2.8 years, height 1.81 ± 0.08 m, mass 84.3 ± 8.7 kg, sum of seven skinfolds 66.6 ± 20.9 mm; mean $\pm$ *s*) provided informed consent and volunteered to participate in the study. Data were collected from 24 Tour games ($7 \times$ Twenty20, $16 \times$ One Day, and $1 \times$ three-day game). The opposition for these games included National "A" teams from New Zealand, South Africa, and India; first-class State teams from Australia (Tasmania) and India (Karnataka); and the Bangladesh and Australian National teams.

Experimental procedures

All participating players were fitted with a MinimaxX (Catapult Innovations, Melbourne, Australia) GPS (5 Hz) unit. The standard error of the estimate (validity) of distance for walking to striding for these units ranged from 0.4 to 3.8%, while the estimate of reliability ranged from 0.3 to 2.9%. For sprinting 20 m, the mean typical error of validity and reliability was 22% (Petersen, Pyne, Portus, & Dawson, 2009).

Using an elasticized shoulder harness, the GPS unit was positioned to sit between the scapulae of the player at the base of the cervical spine. The GPS unit was activated and GPS satellite lock established for at least 15 min before the player took to the field in line with the manufacturer's recommendations. After each session, the game movement data were downloaded using Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) for analysis.

Players were classified as either a bowler or fielder in a particular fielding innings depending on whether they bowled or not. All data was recorded during a fielding innings, including bowling and fielding activity. Fast bowlers performed 4 ± 1 and 7 ± 2 overs bowling per innings for Twenty20 and One Day formats respectively, while in multi-day cricket they bowled 4 ± 2 overs per 2-h session. Twenty20 bowlers and players not bowling (excluding the wicketkeeper) were classified as fielders. It was not possible to analyse the fielder classification further (e.g. close infielders such as a slip, or outfielders such as deep cover, fine leg or third man) due to the frequent and often subtle position changes that occur during the innings. Each player was classified into the following positional or player type: fast bowler, spin bowler, wicketkeeper, fielder or batsman.

Fifteen players opted to wear a heart rate monitor (Polar, Finland) in Twenty20 and/or One Day games (Twenty20: 16 batting, 10 fast bowling, 7 fielding, 3 spin bowling, and 3 wicketkeeping files; One Day: 5 batting and 5 fielding files). After each session, the heart rate data were downloaded using Polar Precision Performance 4.03 software (Polar Electro, Finland) and the maximal and mean heart rates for these files were then determined.

Movement pattern analyses

The following movement categories were established:

- standing/walking 0–2.00 $m \cdot s^{-1}$ (0–7.2 $km \cdot h^{-1}$);
- jogging 2.01–3.50 $m \cdot s^{-1}$ (7.2–12.6 $km \cdot h^{-1}$);

- running 3.51–4.00 $m \cdot s^{-1}$ (12.6–14.4 $km \cdot h^{-1}$);
- striding 4.01 – 5.00 $m \cdot s^{-1}$ (14.4–18 $km \cdot h^{-1}$);
- sprinting $\geq$5.01 $m \cdot s^{-1}$ ($>$18 $km \cdot h^{-1}$).

Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) was used to estimate the cumulative distance covered in each of these movement categories.

In a further level of classification, standing, walking, and jogging were considered ''low-intensity efforts'', while running, striding, and sprinting were considered ''high-intensity efforts''. The ratio of time spent in high- versus low-intensity activity provided a surrogate measure of the work-to-recovery ratio. The numbers and distances (mean, maximum) of sprinting efforts were reported by the Logan Plus software 4.0 (Catapult Innovations, Melbourne, Australia). Adopting a similar approach to Spencer et al. (2004), an episode of repeat sprint activity was defined as a cluster of three or more sprints with less than 60 s recovery between consecutive efforts.

Statistical analysis

Descriptive statistics (mean $\pm$ *s*) were used to characterize the central tendency of the data. To facilitate direct comparison between game formats, player data files during the fielding innings were scaled to movements completed per hour of play. Batting files were also scaled to a 1-h innings, and innings shorter than 20 min were excluded from the analysis.

We used magnitude-based inferences to analyse the time–motion measures (Batterham & Hopkins, 2006). The effect size statistic was generated to characterize the magnitude of difference between positions across the three formats of the game. Briefly, the criteria for interpreting effect sizes were: $<$0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and $>$ 2.0 very large (Hopkins, 2004). Precision of estimation was indicated with a 90% confidence interval (90% CI). The coefficient of variation (CV) expressed as a percentage (%CV) was used to characterize the amount of variability in the time–motion data.

Results

Positional movement patterns and physiological variables

The mean distance covered per hour by players in each position and format of the game is illustrated in Figure 1. Fast bowlers covered the greatest total distance in all game formats. Extrapolating the data to a full 3.5 h of a One Day innings, fast bowlers covered 13.4 $\pm$ 0.7 km (mean $\pm$ 90% CI) in total distance. In comparison, fast bowlers covered

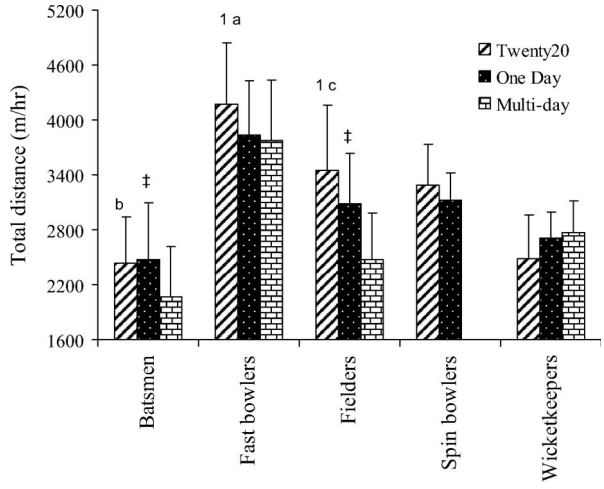


Figure 1. Total distance covered per hour by position in different formats of cricket. [1]Small magnitude of difference within position between Twenty20 and One Day cricket. [a]Small, [b]moderate, and [c]large magnitudes of difference within position between Twenty20 and multi-day cricket. [‡]Moderate magnitude of difference within position between One Day and multi-day cricket.

5.5 $\pm$ 0.4 km in an 80-min Twenty20 innings and 22.6 $\pm$ 2.1 km in a full day of play (3 $\times$ 2 h sessions) of multi-day cricket. Table I summarizes movement categories contributing to this total distance. Fast bowlers covered the greatest distance in striding and sprinting across all formats of the game. During a full One Day innings, fast bowlers covered 1.1 km at sprinting intensities. In comparison, the wicketkeeper travelled the least total distance in a One Day innings, averaging only 9.5 km and covering only 0.1 km at sprinting intensities. However, wicketkeepers covered a greater distance per hour in high-intensity efforts (running, striding, sprinting) in Twenty20 (344 m) than One Day (240 m) or multi-day (109 m) cricket. Batsmen in an entire One Day innings covered 8.7 $\pm$ 0.6 km (mean $\pm$ 90% CI), with 0.5 km covered at sprinting intensity. Batting for a full Twenty20 innings (80 min) batsmen covered 3.5 $\pm$ 0.2 km, while in the unlikely event a batsman bats all day in a multi-day match, an estimated 13.0 $\pm$ 2.0 km would be covered. This workload is in addition to the distances a batsman covered during the fielding innings.

Across all game formats, fast bowlers had the lowest work-to-recovery ratio and the highest number of sprints (Table II). During Twenty20 innings, fast bowlers met the criteria for repeat sprint activity on 3.3 $\pm$ 1.5 occasions with a mean 4.8 $\pm$ 1.4 sprints per bout. In comparison, during One Day and multi-day innings, fast bowlers performed 6.2 $\pm$ 2.9 and 5.5 $\pm$ 4.0 repeat sprint bouts, with a mean 5.0 $\pm$ 1.4 and 4.9 $\pm$ 0.7 sprints per bout, for One Day and multi-day cricket respectively. The number of repeat sprint bouts generally matched the number of overs

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Table I. Movement category distances by playing position and game format (mean ± *s*).

Game format and playing position	Distance covered (metres / hour)				
	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})	Sprinting (≥5.01 m·s^{-1})
Twenty20					
Batsmen ($n=26$)	1638 ± 352[1]	332 ± 103[1,c]	97 ± 35[1,b]	187 ± 70[1,c]	175 ± 97[1,b]
Fast bowlers ($n=18$)	2634 ± 268[1]	718 ± 276[1]	164 ± 76	249 ± 121	406 ± 230[b]
Fielders ($n=26$)	2242 ± 448[1,b]	737 ± 219[1,c]	157 ± 71[1,b]	182 ± 101[1,b]	129 ± 91[1,b]
Spin bowlers ($n=10$)	2317 ± 282	678 ± 210	107 ± 40	109 ± 53	81 ± 55
Wicketkeeper ($n=3$)	1587 ± 139[3,d]	552 ± 166	138 ± 90[c]	147 ± 77[c]	59 ± 23[2,c]
One Day					
Batsmen ($n=36$)	1808 ± 400[+]	279 ± 119[‡]	86 ± 37[+]	154 ± 70[‡]	149 ± 94[‡]
Fast bowlers ($n=24$)	2520 ± 362	618 ± 217	157 ± 58	220 ± 81	316 ± 121[‡]
Fielders ($n=52$)	2117 ± 374[‡]	640 ± 193[‡]	119 ± 46[‡]	124 ± 59[‡]	81 ± 51[+]
Spin bowlers ($n=8$)	2251 ± 239	621 ± 154	116 ± 43	120 ± 63	58 ± 37
Wicketkeeper ($n=6$)	1913 ± 196[‡]	558 ± 104	109 ± 16[†]	97 ± 29[†]	34 ± 21
Multi-day					
Batsmen ($n=9$)	1604 ± 438	200 ± 90	67 ± 18	107 ± 33	86 ± 28
Fast bowlers ($n=10$)	2512 ± 258	614 ± 173	185 ± 89	233 ± 133	230 ± 149
Fielders ($n=20$)	1773 ± 339	480 ± 160	88 ± 43	83 ± 55	52 ± 33
Spin bowlers ($n=0$)					
Wicketkeeper ($n=4$)	2135 ± 151	523 ± 214	51 ± 18	35 ± 24	23 ± 30

[1]Small, [2]moderate, [3]large, and [4]very large magnitudes of difference within position between Twenty20 and One Day cricket. [a]Small, [b]moderate, [c]large, and [d]very large magnitudes of difference within position between Twenty20 and multi-day cricket. [+]Small, [‡]moderate, [†]large, and ⋆very large magnitudes of difference within position between One Day and multi-day cricket.

Table II. Movement variables by playing position and game format (mean ± *s*).

Game format and playing position	No. of sprints per hour	Mean sprint Distance (m)	Maximum sprint distance (m)	No. of efforts per hour	Recovery ratio (1 : *x*)
Twenty20					
Batsmen ($n=26$)	15 ± 9[b]	13 ± 4[1]	19 ± 6[1]	45 ± 16[1,c]	38 ± 13[2,c]
Fast bowlers ($n=18$)	23 ± 10[1,b]	17 ± 4[b]	35 ± 13[2,b]	61 ± 25	25 ± 18
Fielders ($n=26$)	8 ± 5[2,c]	15 ± 4	31 ± 14[a]	42 ± 20[2,b]	43 ± 28[2,b]
Spin bowlers ($n=10$)	5 ± 4	16 ± 5	24 ± 10[2]	25 ± 12[1]	63 ± 36[1]
Wicketkeeper ($n=3$)	5 ± 2[2,b]	13 ± 0	14 ± 6	30 ± 18[c]	51 ± 21[2,d]
One Day					
Batsmen ($n=36$)	13 ± 9[‡]	11 ± 3	21 ± 11	39 ± 16[‡]	50 ± 21[‡]
Fast bowlers ($n=24$)	18 ± 5	18 ± 3[†]	46 ± 12[†]	54 ± 14[+]	25 ± 7
Fielders ($n=52$)	5 ± 3[‡]	15 ± 4	34 ± 14[+]	27 ± 11[‡]	62 ± 41[‡]
Spin bowlers ($n=8$)	4 ± 1	15 ± 5	33 ± 13	29 ± 10	54 ± 16
Wicketkeeper ($n=6$)	2 ± 1	16 ± 9	22 ± 11	23 ± 4[+]	64 ± 18[+]
Multi-day					
Batsmen ($n=9$)	8 ± 3	13 ± 7	21 ± 8	28 ± 6	61 ± 10
Fast bowlers ($n=10$)	17 ± 11	13 ± 1	28 ± 5	56 ± 29	38 ± 31
Fielders ($n=20$)	3 ± 2	16 ± 7	26 ± 14	19 ± 8	90 ± 52
Spin bowlers ($n=0$)					
Wicketkeeper ($n=4$)	2 ± 4	11 ± 19	12 ± 9	12 ± 6	167 ± 73

Note: A sprint is defined as movement above 5 m·s^{-1} for at least 1 s.
[1]Small, [2]moderate, [3]large and [4]very large magnitudes of difference within position between Twenty20 and One Day: [a]Small, [b]moderate, [c]large and [d]very large magnitudes of difference within position between Twenty20 and multi-day: [+]Small, [‡]moderate, [†]large and ⋆very large magnitudes of difference within position between One Day and multi-day cricket.

bowled in Twenty20 (4 ± 1 overs), One Day (7 ± 2 overs), and multi-day (4 ± 2 overs) cricket. No other positional group had more than one repeat sprint bout per innings.

Heart rate data were only collected from a small subset of the players. Based on these data, Twenty20 batsmen had a higher mean heart rate (149 ± 17 beats·min^{-1}) than batsmen playing One Day (144 ± 13 beats·min^{-1}) cricket. Fast bowlers playing Twenty20 cricket had a lower mean heart rate than (133 ± 12 vs. 149 ± 17 beats·min^{-1}), but a similar maximal heart rate to (181 ± 10 vs. 181 ± 14 beats·min^{-1}), Twenty20 batsmen (Figure 2).

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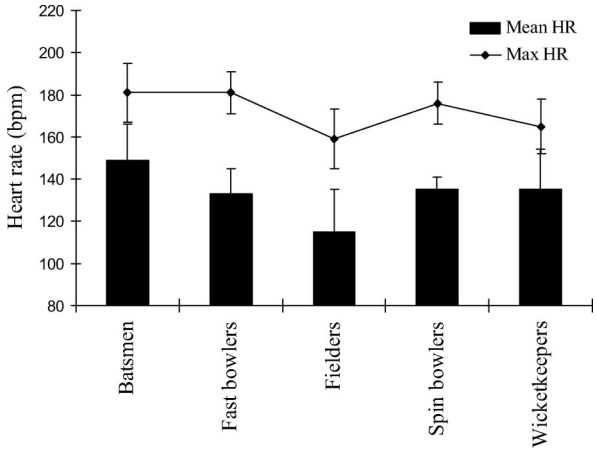


Figure 2. Mean and maximal heart rate (HR; mean $\pm$ *s*) by position in Twenty20 cricket.

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Differences in game formats

The difference in total distance covered per hour between game formats is illustrated in Figure 1. Generally, cricketers covered more distance per hour in Twenty20 than One Day cricket: fast bowlers covered an additional 340 $m \cdot h^{-1}$, fielders 370 $m \cdot h^{-1}$, and spin bowlers 190 $m \cdot h^{-1}$ respectively. In contrast, wicketkeepers covered 230 $m \cdot h^{-1}$ less distance in Twenty20. Comparing Twenty20 with multi-day cricket, fast bowlers covered an additional 400 $m \cdot h^{-1}$, fielders 970 $m \cdot h^{-1}$, and batsmen 370 $m \cdot h^{-1}$ in Twenty20. However, wicketkeepers covered less distance (280 $m \cdot h^{-1}$) in Twenty20 than multi-day cricket. Finally, comparing One Day with multi-day cricket, batsmen (410 $m \cdot h^{-1}$) and fielders (600 $m \cdot h^{-1}$) covered moderately more distance in One Day cricket.

Variability of time–motion and physiological variables

The number of sprints, mean sprint distance, and total distance covered sprinting were the three most variable measures. The coefficient of variation across positions and game formats ranged from 25 to 200%, from 0 to 173%, and from 33 to 130% for number of sprints, mean sprint distance, and distance covered sprinting, respectively. In contrast, the coefficient of variation for total distance only varied by between 9 and 27%. The sprint measures (including maximal sprint distance and number of efforts) were more variable than the physiological (mean and maximal heart rate, lactate) measures. The coefficient of variation ranged from 18 to 75% and from 17 to 60% for maximal sprint distance and number of efforts respectively, while that for heart rate ranged from 3 to 17% and that for lactate ranged from 17 to 38%. The variability in the recovery ratio ranged from 16 to 82% across the different formats of the game.

Discussion

Comparison of motion analysis data

This is the first study to use GPS athlete tracking technology to measure the positional movement patterns together with physiological demands in cricket. Previous studies have used video analysis or computerized tracking to estimate physical demands from either the whole innings (Duffield & Drinkwater, 2008) or a small proportion of the innings (Rudkin & O'Donoghue, 2008). However, these studies were only conducted on one position (batting or fielding) and the time-consuming nature of these approaches limited the sample sizes to 25 and 27 observations respectively. Using GPS technology, we were able to examine 252 observations collected from 42 players over two seasons to evaluate differences between positions and game formats. We acknowledge that only one multi-day game was analysed (the Academy team only played one multi-day game in the 2-year period); however, with $\sim$66 h of game data in total, we believe this adequately reflects the game demands for this format in Academy cricketers.

Total distance proved to be the least variable time–motion characteristic, whereas the number of sprints, mean sprint distance, and distance covered sprinting were the most variable. The volume and duration of sprinting that a player in a particular position undertook appear to depend largely on the game circumstances, whereas walking and jogging played a more consistent contribution to the total distance covered.

Batsmen. Batsmen performed at a similar intensity during Twenty/20 and One Day games, covering a total distance of $\sim$2.6 $km \cdot h^{-1}$, yet during multi-day games they covered 0.4 km less distance per hour (85% of the distance covered in the shorter formats). The volume of work undertaken while batting is directly related to the time a batsman remains at the crease. Theoretically, a batsman that can successfully bat an entire innings will cover $\sim$13.0, 8.7, and 3.5 km in multi-day (6 h), One Day, and Twenty20 cricket respectively.

The work-to-recovery ratio of batsmen during One Day games (1 : 50) in the present study is very similar to that reported by Duffield and Drinkwater (2008) for international One Day batsmen (1 : 47). Additionally, the mean heart rate (144 ± 13 beats $\cdot$ min^{-1}) of One Day batsmen in the present study is almost identical to that reported by Christie et al. (2008) in a study simulating the physiological

demands of international One Day batsmen. These results suggest that batting demands may be similar across performance levels.

Fast bowlers. Of all positions, fast bowlers operated with the greatest intensity across all formats of the game. Compared with other positions, fast bowlers covered 20–80% greater distance, covered 1.8- to 7-fold greater distance during high-intensity movement patterns (sprinting and striding), sprinted more often (1.4–8 times as frequently), and had at least 35% less recovery time between high-intensity efforts. Additionally, the use of the criteria for repeat sprint activity (defined as a minimum of three sprints, with mean recovery duration between sprints of less than 60 s) revealed that only fast bowlers undertook sprinting in clusters. The analysis demonstrates repeat sprint bouts occur during bowling spells, but they can also occur when fast bowlers are performing their fielding duties in between bowling overs. The number of clusters and sprints per cluster bout appears to reflect the bowling spells undertaken in the different game formats (maximum of four 6-ball overs in Twenty20; maximum of ten 6-ball overs in One Day). However, occasionally, the between-over rest period was interrupted with a fielding sprint effort that resulted in two successive overs contributing to the number of sprints in a cluster.

Twenty20 was 22% and 43% more intensive for fast bowlers than One Day and multi-day cricket respectively, in terms of the hourly sprint distance. Yet, the cumulative sprinting in Twenty20 and One Day games was only 39 and 80% of the daily (6 h) 1.4 km sprinted during multi-day cricket.

Twenty20 required 340 and 400 m greater distance per hour from fast bowlers than One Day and multi-day cricket respectively. Yet in absolute terms, fast bowlers covered a total distance of $\sim$22.6, $\sim$13.4, and 5.5 km in multi-day (6 h), One Day, and Twenty/20 innings respectively. Consequently, Twenty20 and One Day cricket required only 24 and 59% of the total distance covered in multi-day cricket.

Comparing fast bowlers' mean heart rates (133 ± 12 beats $\cdot$ min^{-1}) with those of batsmen (149 ± 17 beats $\cdot$ min^{-1}) in Twenty20, the fast bowlers' lower mean heart rate may relate to the extended periods that Twenty20 fast bowlers are in the field (77 ± 17 min) compared with the Twenty20 batsmens' comparably shorter (40 ± 14 min) individual (batting) innings. Both fast bowlers (181 ± 10 beats $\cdot$ min^{-1}) and batsmen (181 ± 14 beats $\cdot$ min^{-1}) in Twenty20 had similar maximal heart rates, which indicates the number of sprints per hour (23 ± 10 vs. 15 ± 9) combined with the respective recovery ratios (1 : 25 vs. 1 : 15) provided sufficient stress to reach similar high heart rates.

Fielders. The intensity of fielding is greatest in Twenty20 cricket, in that One Day and multi-day cricket require only 89 and 72% of the Twenty/20 total hourly distance respectively. It is also important to consider the volume of work undertaken in each format of cricket by taking into account the absolute duration of each type of innings. We estimate that fielders covered $\sim$15 km in 6 h of fielding during a multi-day game, consistent with the estimates of Rudkin and O'Donoghue (2008) that fielders covered 15.5 km in English County cricket. In comparison, fielders in Twenty20 and One Day cricket covered $\sim$4.6 and $\sim$10.8 km in their respective (80 and 210 min) innings.

Spin bowlers. Unfortunately, no spin bowlers wore the GPS devices in multi-day cricket, thus comparisons can only be made between the One Day and Twenty20 game formats. Spin bowlers in Twenty20 and One Day cricket performed a similar amount of sprinting (<100 m $\cdot$ h^{-1}) and covered a similar hourly distance (3.3 and 3.1 km respectively). However, when the duration of the different game formats is taken into account, spin bowlers covered 11.0 and 4.4 km in a One Day and Twenty20 innings respectively.

Wicketkeepers. Surprisingly, wicketkeepers covered more distance per hour (280 and 50 m more) in multi-day than Twenty20 and One Day cricket respectively. However, a greater proportion of total distance covered in the shorter game versions was at higher intensities. Compared with multi-day cricket, wicketkeepers covered 230 and 130 m $\cdot$ h^{-1} more distance at high intensity (running, striding, sprinting) during the shorter game formats of Twenty20 and One Day respectively. Consequently, wicketkeepers enjoyed a substantially longer recovery time between high-intensity efforts in multi-day (167 s) compared with One Day (64 s) and Twenty20 (51 s) cricket. Nevertheless, in absolute terms, wicketkeepers covered a total distance of $\sim$16.6, $\sim$9.5, and $\sim$3.3 km in multi-day (6 h), One Day, and Twenty/20 innings respectively.

Summary. In general, across positions the recovery time between high-intensity efforts is almost a third longer in One Day and twice as long in multi-day cricket compared with Twenty20. Our results indicate that differences in physiological demand exist by position and game format. Further work needs to be undertaken to compare the progression pathway of positional demands from first-class to international cricket.

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Application of motion analysis data

Conducting a time–motion analysis is only the first step in designing more effective sport- and position-specific conditioning programmes. Interpreting and utilizing the data from time–motion studies is a critical step in prescribing an athlete's training programme. Early attempts in field hockey and netball (Huey, Morrow, & O'Donoghue, 2001; O'Donoghue & Cassidy, 2002) to apply time–motion data failed to obtain fitness improvements over and above traditional training. However, for Gaelic Football, King and O'Donoghue (2003) demonstrated that match-specific training (varying burst length and recovery periods to reflect those used in competition) based on GPS time–motion data incorporating progression and overload was a more effective conditioning method than traditional fitness training. Future studies should investigate whether time–motion based training (incorporating set work-to-recovery ratios and frequency of sprints) is more effective than traditional cricket training (non-specific fitness training combined with long net batting and bowling sessions) in improving cricket-specific fitness.

Most team sport athletes spend more time involved in training than in competition. However, this may not apply to elite cricketers. For example, Australian national team players had a total of 90 ($2 \times$ Twenty20, $18 \times$ One Day, and $14 \times$ Test matches) possible competitive playing days in the 2008 calendar year. This number is likely to increase with newer franchise-based competitions (e.g. Indian Premier League, Indian Cricket League) extending the playing opportunities for international players. With a shorter off-season to improve fitness, in-season fitness maintenance becomes even more important. Contemporary in-season training practices combined with game demands are not generally sufficient to maintain endurance fitness (9% decrement) through a first-class season (Petersen, Pyne, Portus, & Dawson, 2008). The unpredictable nature of games usually dictates that a player will not train on a match day, thus in-season conditioning work must be undertaken primarily on non-playing days and scheduled around travelling requirements. Conditioning coaches may use detailed information on the game-to-game demands of players to balance conditioning and recovery activities to minimize fitness decrements, while maximizing physical performance during games.

Conclusion

The demands of cricket varied substantially by both player position and game format. Fast bowlers had the greatest workloads across all formats of the game, and Twenty20 cricket was more intense for all positions. While the intensity of the game increases for all positions with the shorter game formats, the longer duration of multi-day cricket elicits a much larger overall physical load. The movement data of this study indicate that cricket is a highly intermittent short sprint sport with a substantial base of low-intensity activity. This study provides detailed match demand values for cricket conditioning coaches, and careful application of these data should enhance the development and modification of position-specific conditioning programmes.

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Chapter 5

Analysis of Game Demands

Study 7: Comparison of player movement patterns between 1-day and test cricket.

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Comparison of Player Movement Patterns Between 1-Day and Test Cricket

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Abstract

Petersen, CJ, Pyne, DB, Portus, MR, and Dawson, BT. Comparison of player movement patterns between 1-day and test cricket. *J Strength Cond Res* 25(5): 1368–1373, 2011—Physical demands of cricket presumably vary by both game format and performance level. Differences in player movement patterns between 2 game formats (1 day and multiday) and 2 levels of elite performance (state and international) were quantified with global positioning system technology. Five movement categories were established, and 15 movement pattern variables were reported. Data from state ($n = 42$, 200 files) and international ($n = 12$, 63 files) cricketers were scaled to hourly values to compare movement demands. Cricketers generally covered similar distances in both formats, except for state 1-day fielders who covered moderately greater distance (~0.7 km·h^{-1} more; 21 ± 8%; mean ± 90% confidence interval) than state multiday (first-class) fielders. State 1-day cricketers also covered small to moderately greater distances (running 41 ± 13%; striding 38 ± 16%; sprinting 39 ± 36%) in the faster movement patterns and consequently had moderately less recovery time (13–67%) between high-intensity efforts as first-class cricketers. Comparisons of movements between performance levels revealed similar total distances between state and international cricketers. However, Test fielders covered moderately greater (29–48%) distances at the higher-intensity movement patterns (running, striding, and sprinting) than first-class fielders. In summary, although movement patterns were broadly similar between formats and levels, it appears that one day cricket (compared with multiday games) and test matches (compared with state-level competition) require more higher-intensity running. Conditioning coaches should train state and international 1-day cricket players similarly, but should account for the higher physical demands of international multiday cricket.

Key Words fast bowling, fielding, batting, Global Positioning System

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Introduction

Conditioning coaches monitor the workload or game demands of players in most sports to balance the amount of conditioning and recovery. Elite cricketers participate in a mixture of 1-day and multiday games at either the domestic (state) or international level during a long competitive season. Some cricketers also play in lucrative Twenty20 (T20) league cricket. However, methods to quantify differences in physical demands between the various game formats and levels of performance in cricket are lacking. Time–motion data on the movement demands of elite cricketers is needed to assist conditioning coaches develop periodized training plans.

Cricket is unique in that 3 different formats are played at the elite level (T20, 1 day and multiday). Different names are given to various types of games; international 1-day cricket is called 1-Day International (ODI), whereas domestic 1-day cricket is simply called 1-Day cricket. In the multiday formats, 4-day (termed first-class) cricket is played domestically, whereas 5-day Test cricket is played between international teams. Twenty20 cricket is the shortest format and is simply called T20 domestic or T20 international depending on the respective level of competition. The emerging formats of the game, and the pace of development, are challenging conditioning coaches' prescription of game-specific conditioning and recovery programs.

Conducting a time–motion analysis of a sport's movement patterns is a common precursor for designing conditioning programs. In cricket, this practice is relatively new and the first 2 published studies using video analysis appeared in 2007. The first study investigated first-class (English County) fielding of the cover-point position in 3 games (27 observations) and predicted fielders cover 15.5 km in a 6-hour day (9). In the second study, the movement patterns of 18 batsmen scoring a century in ODI ($n = 5$) or Test ($n = 13$) cricket were investigated: ~99% (Test) and 98% (ODI) of the batsmen's time was spent in stationary, walking, and jogging movement patterns (3). The time-consuming nature of these video-based studies resulted in only comparatively small sample sizes. However, with the increased reliability and the practical convenience of Global Positioning System (GPS) monitoring, notational analysis and manually controlled computer tracking software in sports is being superseded by GPS technology (7).

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A GPS unit receives time signals from a network of 27 operational satellites in orbit around the earth. The satellites first set the clock in the GPS unit by synchronizing it with the atomic clock in the satellite and then constantly send information (at the speed of light) about exact time to the receiver. The distance to the satellite is then calculated by multiplying the signal travel time with the speed of light. By calculating the distance to at least 4 satellites, the exact position can be trigonometrically determined. Movement speed can also be determined by dividing the differences in cumulative distance with the time difference between 2 logged positions (5).

Wearable GPS devices have recently been used to quantify the positional demands of academy cricketers during 3 different game formats (T20, 1 day, and multiday) (8). In this study the shorter game formats (T20 and 1 day) were more intensive per unit time, but multiday cricket had a greater overall physical load (8). However, there has been no comprehensive time–motion study of the performance level demands of elite cricketers (international and state cricketers) during 1-day (1-day domestic and ODI) and multiday (first-class and Test) cricket. This study provides the first comprehensive quantitative description of the movement demands undertaken by elite cricketers. Using these data, conditioning coaches can individualize training and recovery strategies to reflect positional match demands. The aim of this study was to quantify differences between formats and playing level in the movement patterns of international- and state-level cricketers.

Methods

Experimental Approach to the Problem

Global positioning system (5 Hz) player tracking units (Catapult Innovations, Melbourne, Australia) were used in a prospective observational study over 2 seasons to quantify movement patterns of game play in 2 formats (1 day and multiday) at 2 performance levels (state and international) of cricket.

Subjects

Australian international ($n = 12$; age 29.8 ± 3.6 years; height 1.85 ± 0.06 m; mean ± *SD*) and state ($n = 42$; age 27.1 ± 3.3 years; height 1.83 ± 0.07 m) cricketers provided written informed consent after explanation of all the experimental procedures and volunteered to participate in this study. A total of 263 GPS game files were collected from fast bowlers and fielders in 28 in-season competitive matches (International: 14 × ODI, 3 × Test matches; State: 6 × 1-day, 5 × first-class matches). All players were assessed as fully match-fit before being selected to represent their state or country. The opposition for these games included the Indian, Bangladesh, New Zealand, and Sri Lankan national teams and domestic games between all 6 Australian state teams. All matches occurred between 10 AM and 10 PM, players had unlimited access to both water and sports drinks during games and meals were provided for all players. Approval for the study was provided by the Ethics Committee of the Australian Institute of Sport.

Procedures

All participating players were fitted with a MinimaxX (Catapult Innovations, Melbourne, Australia) 5-Hz GPS unit positioned inside an elasticized shoulder harness to sit between the scapulae of the player at the base of the cervical spine. For these units, the standard error of the estimate (validity) of distance for walking to striding is 0.4–3.8%; and reliability from 0.3 to 2.9% (7). For sprinting, the mean typical errors in validity and reliability of estimating distances over 20 m were 22% (7). After each session data were downloaded using Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) for analysis. The following movement categories were established: (a) standing or walking 0–2.0 $m \cdot s^{-1}$ (0–7.2 $km \cdot h^{-1}$); (b) jogging 2.0–3.5 $m \cdot s^{-1}$ (7–12.6 $km \cdot h^{-1}$); (c) running 3.5–4.0 $m \cdot s^{-1}$ (12.6–14.4 $km \cdot h^{-1}$); (d) striding 4.0–5.0 $m \cdot s^{-1}$ (14.4–18 $km \cdot h^{-1}$); (e) sprinting 5.0 $m \cdot s^{-1}$ + (>18 $km \cdot h^{-1}$) and the cumulative distance covered in each of these movement categories was determined. Additionally, running, striding and sprinting were categorized as "high-intensity efforts" and the number, mean duration, and recovery time between these efforts was determined. Finally, each player was classified (depending on whether they actually bowled in that innings) into the following positional or player types: fast bowler or fielder. Comparison of movement characteristics between multiday (First class and Test) cricket was only possible with fielders, because of the limited number of Test fast bowlers willing to wear the GPS units. Given the small number of files collected from batsman, spin bowlers, and wicketkeepers, these categories of players were excluded from the final analysis.

Statistical Analyses

Descriptive statistics (mean ± *SD*) were used to characterize the central tendency of the data. Movement data were scaled to hourly values to facilitate direct comparison between game formats. Player data files were also scaled to movements completed per innings (210 minutes for ODI and 1-day domestic) or per session (120 minutes for both first-class and test matches) to compare total game load and differences between state and international competitions.

We adopted the approach of magnitude-based inferences to analyze the time–motion data (1). The effect size statistic (ES) was generated to assess the magnitude of difference between game formats or competition levels in each movement pattern category. The criteria for interpreting effect sizes were <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and >2.0 very large (4). Precision of estimation was indicated with a 90% confidence interval. The coefficient of variation (%CV) was used to characterize the degree of variability in the time–motion data.

Results

Tables 1 and 2 detail the hourly movement characteristics during state and international games, respectively. A comparison of the

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Table 1. Hourly physical demands of State 1-day and First class (State 4-day) fielding and fast bowling.*

	Fast bowling		Fielding	
Workload variable	State 1 day ($n = 8$)	First class ($n = 80$)	State 1 day ($n = 18$)	First class ($n = 94$)
Distance				
Walking (0–2.0 m·s^{-1}) (m)	2,626 ± 297	2,810 ± 487†	2,388 ± 379†	2,116 ± 562
Jogging (2.0–3.5 m·s^{-1}) (m)	684 ± 158‡	574 ± 185	773 ± 171‡¶	520 ± 228
Running (3.5–4 m·s^{-1}) (m)	154 ± 40‡	118 ± 42	159 ± 34‡#	104 ± 48
Striding (4.0–5.0 m·s^{-1}) (m)	216 ± 47†	187 ± 65	169 ± 42‡#	117 ± 60
Sprinting (5+ m·s^{-1}) (m)	344 ± 93†	334 ± 134	138 ± 65†¶	96 ± 64
Total distance (m)	4,026 ± 496	4,024 ± 716	3,627 ± 535‡	2,954 ± 822
Time				
Walking and jogging (s)	3,414 ± 40	3,448 ± 104†	3,470 ± 59	3,504 ± 72†
Running, striding, and sprinting (s)	149 ± 22†	132 ± 40	107 ± 25‡#	73 ± 32
Sprint				
Number (#)	20 ± 3	20 ± 7	8 ± 4‡#	5 ± 3
Mean sprint distance (m)	17 ± 3	17 ± 3	15 ± 3	17 ± 6†
Maximum sprint distance (m)	42 ± 13	44 ± 12	42 ± 17	37 ± 18
Maximum sprinting speed (m·s^{-1})	8.1 ± 0.5	8.4 ± 0.7†	8.4 ± 1.1†#	7.7 ± 1.2
High-intensity efforts				
Number (#)	53 ± 8†	50 ± 22	39 ± 9‡#	26 ± 13
Mean effort duration (s)	2.8 ± 0.2†	2.7 ± 0.4	2.8 ± 0.3#	2.9 ± 0.6
Recovery between (s)	69 ± 10	83 ± 35‡	99 ± 28	188 ± 134‡¶

*Values are mean ± *SD*.
†Small magnitudes of difference between game formats.
‡Moderate magnitudes of difference between game formats.
¶Moderate magnitudes of difference between performance levels.
#Small magnitudes of difference between performance levels.

hourly distance covered by fast bowlers in 1-day domestic and first-class cricket reveals that the (scaled) total distance was ~4 km·h^{-1}, with a sprint distance of 0.3 km·h^{-1}, in both game formats. Likewise, fielders covered 3.0–3.6 km·h^{-1} with only ~0.1 km·h^{-1} at sprinting intensity in both game formats. Fielders in international cricket covered a similar hourly distance (3.4 vs. 3.3 km·h^{-1}) in ODI and Test formats, with <0.2 km·h^{-1} at sprinting intensity.

Tables 1 and 2 also indicate the magnitude of difference between state and international cricket across the different playing positions. Extrapolating the data to the absolute movement characteristics covered in an innings of 1-day (1-day domestic and ODI) or a session of multiday (first class and Test) cricket respectively, reveals the following: fast bowlers in 1-day domestic and ODI cricket covered 14.1 ± 1.7 and 15.0 ± 2.4 km (mean ± *SD*) in an innings, respectively, with 1.2 ± 0.3 km at sprinting intensity for both levels of performance. The only substantial difference between the movement patterns of fast bowlers was that ODI fast bowlers covered moderately greater distance (~1.1 km more; 12%; ES: 0.63 ± 0.59) walking than 1-day domestic fast bowlers. Fielders in ODI and 1-day domestic cricket covered 12.0 ± 3.1 and 12.7 ± 1.8 km, respectively, with 0.3 ± 0.3 and 0.5 ± 0.2 km covered at sprinting intensity. Surprisingly, 1-day domestic fielders covered small to moderately greater distances (6–54%; ES: 0.40–0.77) in the faster movement patterns (jogging to sprinting) than ODI fielders.

In multiday cricket, fielders covered 5.9–6.7 km with 0.2–0.3 km at sprinting intensities. There were small to moderately greater distances (7–42%; ES: 0.24–0.77) covered across all movement patterns at the international (Test) compared with the state (first-class) performance level. Test fielders also had a moderately greater (68 vs. 51; ES: 0.70 ± 0.27) number of high-intensity efforts, with moderately less mean recovery time (116 vs. 188 seconds; ES: 0.70 ± 0.27) between these high-intensity efforts as first-class fielders.

There was substantial variability in the time motion measures of 1-day and multiday cricket. For 1-day (ODI and 1-day domestic) cricket the 2 most variable categories were the distance covered sprinting (CV range 26–137%) and the number of sprints (16–113%). The 2 least variable measures were the time spent walking and jogging (1–2%) and the total distance covered (14–32%). Similarly, for multiday (first-class and Test match) cricket, the 2 most variable time–motion measures were the number of sprints (range 55–102%) and the distance covered sprinting (range 61–149%). The least variable measures were time spent

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Table 2. Hourly physical demands of ODI and Test (International 5-day) fielding and fast bowling.*†

Workload variable	Fast bowling ODI ($n = 21$)	Fielding ODI ($n = 17$)	Fielding Test ($n = 25$)
Distance			
Walking = 0–2.0 $m \cdot s^{-1}$ (m)	2,936 ± 539‡	2,419 ± 708	2,263 ± 629§
Jogging = 2.0–3.5 $m \cdot s^{-1}$ (m)	648 ± 220	616 ± 272	621 ± 135§
Running = 3.5–4 $m \cdot s^{-1}$ (m)	145 ± 39	147 ± 62	137 ± 44‡
Striding = 4.0–5.0 $m \cdot s^{-1}$ (m)	208 ± 53	159 ± 89	166 ± 62‡
Sprinting = 5+ $m \cdot s^{-1}$ (m)	341 ± 76	90 ± 73	155 ± 71‖‡
Total distance (m)	4,279 ± 677	3,430 ± 883	3,342 ± 759§
Time			
Walking and jogging (s)	3,444 ± 36‡	3,504 ± 46‡	3,496 ± 30
Running, striding and sprinting (s)	143 ± 27	91 ± 45	104 ± 30¶‡
Sprint			
Number (#)	19 ± 4	6 ± 4	8 ± 4‖‡
Mean sprint distance (m)	18 ± 3§	15 ± 4	18 ± 5‖§
Maximum sprint distance (m)	49 ± 17	34 ± 12	43 ± 15¶§
Maximum sprinting speed ($m \cdot s^{-1}$)	8.2 ± 0.8	7.9 ± 1.2	8.5 ± 0.9¶‡
High-intensity efforts			
Number (#)	52 ± 11	34 ± 17	34 ± 11‡
Mean effort duration (s)	2.8 ± 0.2	2.6 ± 0.3	3.1 ± 0.3‖§
Recovery between (s)	73 ± 21	134 ± 73§	116 ± 37

*ODI = 1-day international.
†Values are mean ± *SD*.
‡Moderate magnitudes of difference between performance levels.
§Small magnitudes of difference between performance levels.
‖Moderate magnitudes of difference between game formats for the fielding position.
¶Small magnitudes of difference between game formats for the fielding position.

walking and jogging (range 1–3%) and maximum sprinting speed (range 9–17%).

Discussion

Cricket conditioning coaches are seeking detailed game analysis to increase the specificity of training drills and recovery interventions for both 1-day and test cricket. Elite cricketers play a mixture of 1-day and multiday games and more accomplished players also play a combination of first-class and international cricket. Multiday cricket, had an absolute greater physical load, yet with the exception of state 1-day fielders, had a similar physical intensity as 1-day cricket. The intensity of international cricket was higher in the multiday format; however, in 1-day cricket players had similar physical demands between performance levels. These findings should be useful for conditioning coaches to prescribe specific conditioning and recovery work.

Cricketers are unique in that they play a mixture of game formats, ranging from 3 hours to 5 days. This analysis has primarily focused on comparing the intensity or hourly movement demands of 1-day (7 hours) and multiday games. However, from a conditioning point of view, it is important to also consider the total volume of these different formats of cricket when planning and modifying training programs. Training and recovery interventions in the short- and medium-term ultimately depend on the likely absolute game load.

In state-level cricket, the intensity of 1-day cricket (fast bowling and fielding) is greater than the multiday cricket format. However, with fielding at the international level, there was little difference between ODI and Test formats. Future analysis will determine if this finding also applies to international fast bowlers. Differences in the rules between formats may be a factor. For example, the game load of fast bowlers is influenced by the bowling restrictions in one day cricket (bowlers are limited to 10 overs per game). Multiday fast bowlers are therefore likely to bowl a greater number of overs per hour; however, as seen with state-level fast bowlers this potential for a greater work rate may not be utilized. Research highlights fast bowlers miss through injury, about 16% of all potential playing time (5). Risks for bowling injury include a greater injury risk in the second innings of a game, or when the follow on rule is enforced in a test match (6). Furthermore, there appears to be a dual fast bowling threshold beyond which the injury risk increases and maintaining a workload that is too low (<123 deliveries per week) or infrequent (5 or more days between bowling sessions) is an equally significant risk factor as maintaining a high bowling workload (>188 deliveries per week, or <2

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days between bowling sessions) (2). Elite captains tend to be well aware of these facts and the importance of managing their fast bowlers' bowling workload.

Overall, the duration of 1-day cricket (3.5 hours) is only ~60% of the daily fielding required in multiday cricket (3- × 2-hour sessions). Nonetheless, in absolute terms multiday cricket required 40–70% (5–10 km) more distance in a day, which highlights the greater overall physical load of multiday cricket. Multiday cricketers need the endurance to sustain physical performance over 6 hours and as over multiple days. Additionally, multiday fast bowlers at certain times (when performing extended bowling spells) may perform for long periods during the day at a much greater intensity than fast bowlers in 1-day cricket.

There are similar patterns of movement in 1-day cricket between state and international games. The only clear differences, yet practically inconsequential, were that ODI fast bowlers covered moderately greater ground (~1.1 km more; 12%) walking than state 1-day fast bowlers, and state 1-day fielders had small to moderately (8–53%) higher physical demands per innings at the higher-intensity movement patterns, than ODI fielders. Given the low intensity of walking, and the modest absolute distances involved at the higher-intensity movement patterns (differences of <0.2 km), these differences between 1-day performance levels are practically irrelevant to conditioning.

In multiday cricket, there were clear differences in movement demands between performance levels. Comparisons between first-class and Test fielders showed that per day, Test fielders had moderately higher demands in the distance covered running (198 ± 103 m more), striding (296 ± 139 m more) and sprinting (351 ± 159 m more), and a moderately higher number of sprints (17 ± 8 more) and high-intensity activity efforts (50 ± 26 more). Test cricket is widely regarded as the pinnacle of cricket, consequently, the increased importance, rewards (prestige, financial) and exposure (larger number of ground spectators and television exposure of millions) may explain the increased effort and movement intensity of the international fielders. Future work is needed to determine whether other positions in Test cricket also have higher physical demands. Irrespective of why these differences occur, conditioning coaches are able to use these data to obtain insights into the demands faced by their players playing domestic or international cricket).

Recent data (8) demonstrate increased physical game demands from the academy to international competitive levels. Academy level fast bowlers cover an estimated 22.6 ± 4.0 km (mean ± *SD*) in a day (3- × 2-hour sessions), whereas we estimate first-class fast bowlers cover 24.1 ± 4.3 km·d^{-1}. Similarly, for first-class and Test fielders our estimate of a daily total distance of 17.7 ± 4.9 and 20.0 ± 4.6 km, respectively, is greater than the 14.9 ± 3.0 and 15.5 km estimated for academy level (8) and English county fielders (9), respectively. Likewise, comparisons between academy level and senior elite 1-day cricket show a similar trend. Academy-level fast bowlers cover ~11–15 km in a 1-day innings, whereas 1-day state and ODI bowlers cover 13–17 km. Overall, international cricket required 12–34% greater physical demand than academy level cricket.

Cricketers experience substantially different workloads depending on their role within a particular game. Understanding the degree of variability in the different workload measures enables conditioning coaches to prescribe position-specific low-, medium-, and high-intensity training drills and activities. Although the total distance covered in a game (meters or kilometers) is intuitively appealing, the low game-to-game variability of this measure prevents the distinction between an easy and hard game, in terms of physical demand. In contrast, sprinting distance has greater game-to-game variability enabling the classification of overall game physical demand; however, the reduced reliability and validity of this measure (7) need to be taken into account. The combination of total and sprinting distance should enable conditioning coaches to confidently prescribe interval-based conditioning training.

Practical Applications

Assessing the game load that cricketers undertake is important for conditioning coaches wishing to prescribe training drills and recovery interventions between matches. Elite cricketers often play a mixture of international- and state-level cricket within the same season. The international or state conditioning coach must take into account the prior game load to ensure an appropriate training load is prescribed. Furthermore, cricket is unique with players often involved in different types of game formats ranging in duration from 3 to 5 days. Our data reveal that only fielders in state 1-day cricket (who required 19–53% greater intensity in the faster movement patterns) operated at a higher-intensity than in multiday cricket. Multiday cricket elicited a higher load at the international level. Conditioning coaches should train state and international 1-day cricket players similarly but should account for the higher physical demands of international multiday cricket. With similar intensity across game formats, the much longer duration of multiday cricket is the primary consideration in prescribing training and recovery. Conditioning coaches can also use these movement pattern data in combination with the season schedule to periodize training through the off-, pre, and competitive-seasons.

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Chapter 6

Analysis of Training Demands

Study 8: Comparison of training and game demands of national level cricketers.

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Comparison of Training and Game Demands of National Level Cricketers

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Abstract

Petersen, CJ, Pyne, DB, Dawson, BT, Kellett, AD, and Portus, MR. Comparison of training and game demands of national level cricketers. *J Strength Cond Res* 25(5): 1306–1311, 2011– Although the physiological demands of cricket match play are emerging, the demands of contemporary training practices have not been reported. The aim of this study was to quantify the physiological demands of selected cricket training activities and compare these to known match demands. Twenty-eight different training activities were monitored in national academy level cricketers ($n = 42$) using global positioning system units during a 14-week residential training program. The training activities were classified into 3 categories: conditioning sessions ($n = 8$), skill sessions ($n = 9$), and game simulations ($n = 11$). Conditioning sessions were further classified into high- ($n = 4$) and low- ($n = 4$) intensity drills. Time–motion measures included movement patterns (walk, jog, run, stride, and sprint distances), total distance covered, number of sprints, number of high-intensity efforts, maximum speed, and recovery time between high-intensity efforts. Inferential statistics were used to quantify magnitudes of difference between various training drills. Movement patterns were then compared to recently published game data (Twenty20, One-Day, and Multiday games) from the same sample group of cricketers. Conditioning drills were twice as long in duration as skill drills and twice as intense as both the skill and game simulation drills. Exercising heart rates were 9–26% and lactate levels up to 3.5 times higher in conditioning compared to other training drills. Conditioning drills matched or exceeded (up to 10 $b \cdot min^{-1}$; 5%) peak game heart rates. Conversely, skill and simulation drills replicated mean game heart rates for some, but not all positions. In conclusion, training replicates or exceeds cricket match demands in conditioning-type drills but not in simulation or skill-based drills. Modification of skill and simulation training drill practices will ensure closer replication of match and training demands.

Key Words batting, bowling, fielding, global positioning system, Twenty20

Introduction

Only recently have the physiological demands of cricket match play received scientific attention. In contrast, there is little published information on the physiological demands of common cricket training activities. Modern elite cricketers undertake several types of training practices encompassing skill and technique work, conditioning drills, and simulated matches. Many coaching texts describe technical aspects of cricket skill development, with some including strength and conditioning programs for developing fitness levels to enhance performance and reduce the risk of injury (10,34). However, to date, there has been no examination of whether training drills replicate the physiological demands of actual competition.

Time–motion analysis in cricket is a relatively recent practice. Fletcher conducted early investigations into the average energy expenditure of Test cricketers in 1955. However, it was not until 53 years later that energy expenditure in cricketers was revisited with a simulated study of batsmen (5). Since then, several studies have analyzed the time–motion characteristics of different aspects of cricket game play using either video (9,29) or global positioning system (GPS) methods (21–23). These studies have quantified the actual distances covered and the movement speeds of players during cricket match play. Additionally, these studies have investigated the time–motion characteristics of single cricket positions–cover point and batting (9,29), and the differences between positions (batsmen, fast bowlers, fielders, spin bowlers, and wicketkeepers) (21,22), game formats (21), and the between-game variability of movement demands of a single fast bowler (23). Various physiological responses (e.g., core temperature, heart rate, sweat rate, urinary osmolarity, thermal sensation, ratings of perceived exertion [RPE], bowling speeds, creatine kinase activity, lower body power, blood lactate, % dehydration and

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hydration status) during actual match play (3,15,31) or during simulated intense components of match play (4,5,8,25,32) have been quantified. The relative lack of scientific research into 1 of the world's oldest organized sports and the need to study the fitness requirements and physical preparation has been highlighted for at least a decade (19).

Anthropometric characteristics of elite cricketers are related to performance measures such as bowling speed (25,27,33). Other research has focused on subtle technical factors that may enhance skilled technique (1,11,14,25) or on visual cue recognition to enhance batting reaction time (17,18). Additionally, comprehensive studies have been undertaken detailing bowling (7) and throwing (30) workloads undertaken by cricketers in both match play and in training and how these workloads relate to injury risks. Intervention studies directed at enhancing cricket bowling velocity (24) or throwing velocity (12) have also been performed.

Despite these recent research studies into cricket, little attention has been paid to the physical demands and variety of cricket training activities performed by elite cricketers. An analysis of the effectiveness of training activities in replicating sport-specific movement patterns is a logical process that has been undertaken in several other sports including Australian Football (6), rugby league (13), and tennis (28). The purpose of this paper was to quantify the time–motion and physiological characteristics of different types of cricket training practices and compare them with the established physiological demands of cricket.

Methods

Experimental Approach to the Problem

A longitudinal observational study was undertaken over a 14-week residential off-season (winter) program of Australian Academy cricketers. These are highly trained cricketers targeted to represent the Australian senior national team in the near future. The training program culminated in a home tournament, the Cricket Australia Emerging Players Tournament (EPT) and a short domestic tour (Darwin, Australia) to play the Bangladesh and Australian National teams. Players had their time–motion and physiological variables monitored while undertaking the full variety of training activities. The demands of training were then compared with published game data obtained from the EPT tournaments played in 2007 and 2008.

Subjects

Male cricketers ($n = 42$, 22.1 ± 2.8 years; height 1.81 ± 0.08 m; mass 84.3 ± 8.7 kg; sum of 7 skinfolds 66.6 ± 20.9 mm; mean ± *SD* age) provided written informed consent after explanation of all the experimental procedures and volunteered to participate in this study. All training occurred between 9 AM and 4 PM, players had unlimited access to water and sports drinks, and breakfast and lunch were provided for all players. Data were collected from 28 cricket drills and classified into 1 of 3 types of training activities (game simulations $n = 11$, skill sessions $n = 9$, and conditioning sessions $n = 8$). Skill drills were classified as drills that are intended to train isolated technical aspects of game play, like catching. Game simulations are drills designed to practice skills under game-like conditions, and finally, conditioning drills are designed to enhance the fitness of the players. The conditioning sessions were further divided (using a 7 mmol·L^{-1} lactate threshold) into high ($n = 4$) and low ($n = 4$) intensity drills. Warm-ups were analyzed separately and are only reported in the text of the results. The types of sessions and number of participants in each drill are listed in Table 1. The Ethics Committee of the Australian Institute of Sport provided approval for the study.

Procedures

All participating players were fitted with a MinimaxX (Catapult Innovations, Melbourne, Australia) GPS (5-Hz) unit. The standard error of the estimate (validity) of distance for walking to striding for these units ranged from 0.4 to 3.8%, whereas the estimate of reliability ranged from 0.3 to 2.9%. For sprinting 20 m, the mean error of validity and reliability was 22% (20).

The GPS unit was positioned via an elasticized shoulder harness to sit between the scapulae of the player at the base of the cervical spine. The GPS unit was activated and GPS satellite lock established for at least 15 minutes before the player taking the field as per the manufacturer's recommendations. After each session, the training movement data were downloaded using Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) for analysis.

Nine players also opted to wear a heart rate monitor (Polar Electro Oy, Oulu, Finland) in most training sessions (data collected from 22 training sessions, total of 145 files). The heart rate data were downloaded using Polar Precision 4.0 software (Polar) for determination of mean and maximal heart rates. During 14 drills, capillary blood samples (5 μl) were collected from players ($n = 15$) and analyzed using a Lactate Pro blood-lactate analyzer (Arkray, Kyoto, Japan). Samples were collected within 2 minutes of completing a drill. The correlations between the Lactate Pro and the ABL 700 Series Acid–Base analyzer, YSI 2300 and Accusport were $r = 0.98$, $r = 0.99$, $r = 0.97$. Although the correlation between the 2 Lactate Pro analyzers on the same sample ($n = 96$ cases) was $r = 0.99$ (26).

The following movement categories were used; (a) standing or walking 0–2 m·s^{-1}(0–7.2 km·h^{-1}); (b) jogging 2–3.5 m·s^{-1} (7.2–12.6 km·h^{-1}); (c) running 3.5–4 m·s^{-1} (12.6–14.4 km·h^{-1}); (d) striding 4–5 m·s^{-1} (14.4–18 km·h^{-1}); (e) sprinting 5 m·s^{-1}+ (>18 km·h^{-1}+) as employed in several cricket match analysis papers (21–23). Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) was used to estimate the cumulative distance covered in each of these movement categories. In a further level of classification, standing, walking, and jogging were considered "low-intensity efforts," whereas running, striding, and sprinting

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Table 1. Description and duration of commonly used training drills for improving fitness and skill of cricket players.*

Drill (no. of observations)	Duration (min ± *SD*)	Description
High-intensity conditioning sessions		
GPS running (4)	38	Game-specific movements
Sprint session (19)	46 ± 5	Sprint quality
Square run (7)	24	Timed varied intensity efforts over 20–60 m
Tabata–bike (6)	45	20-s work, 10-s rest × 8–(8 sets)
Low-intensity conditioning sessions		
Fast bowler sprints (3)	47 ± 1	Run-up replication
Field conditioning (5)	29 ± 2	Fielding skills and fitness activities
Sprint endurance (8)	40 ± 8	High-intensity running
Sprint technique (12)	46	Sprinting technique drills
Game simulations		
Bat–30 over (6)	35 ± 24	Batting–game simulation
Bat–open wicket (5)	13 ± 2	Batting–game simulation
Bat–scenario (8)	19 ± 9	Batting–changing game tempo
Fast bowl–scenario (4)	19 ± 11	Fast bowling–various instructions
Fast bowl open wicket (2)	40 ± 4	Fast bowling–game simulation
Field–30 over (6)	101 ± 9	Fielding–game simulation
Field–scenario (24)	22 ± 8	Fielding–under different situations
Spin bowl open wicket (2)	68	Spin bowling–game simulation
Spin bowling scenarios (3)	27	Bowling–under different instructions
Wicketkeeping 30 over (1)	105	Wicketkeeping–game simulation
Wicketkeeping scenarios (3)	20 ± 10	Wicketkeeping–various instructions
Skill session		
Boundary fielding (9)	13 ± 2	Boundary fielding skills
Crouched catches (14)	4 ± 1	Short fast reaction catches
Fielding session (10)	49 ± 11	Fielding skills
Ground in-fielding (24)	11 ± 2	Fielding in the circle–skills
High catches (24)	17 ± 4	High catching practice
Net batting (10)	20 ± 8	Batting against bowling machines/bowlers
Net fast bowling (6)	26 ± 5	Bowling to batsmen in nets
Net spin bowling (1)	26	Bowling to batsmen in nets
Partner throwing (25)	9 ± 0	Medium range 20- to 30-m throws
Warm-up (21)	13 ± 1	General movement and stretches

*GPS = global positioning system.

were considered "high-intensity efforts." The mean recovery time between high-intensity efforts was determined by dividing the number of high-intensity efforts by the total session duration.

Statistical Analyses

Descriptive statistics (mean ± *SD*) were used to characterize the physiological effect of a variety of training activities, with the physiological demands from actual cricket match play. The coefficient of variation expressed as a percentage (%CV) was used to characterize the degree of variability in the time–motion data of training drills. The effect size (ES) statistic was used to quantify the magnitude of difference between high-intensity conditioning and other types of training drills. Briefly, the criteria for interpreting ESs were <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and >2.0 very large (16). Clear effects were inferred when the 90% confidence interval did not overlap both substantial positive and negative values (2).

Results

Warm-ups were analyzed separately from training drills and had a duration of 13 ± 1 minutes (mean ± *SD*) and consisted of general low-intensity movements followed by static and dynamic stretching. The activities included throwing movements of progressive intensity or Thera-Bands™ to warm up the glenohumeral joint in particular.

Training Drill Movement Patterns Measures

Table 1 provides a description and classification of each training drill. Table 2 details the positional movement characteristics during 4 types of training drills. Conditioning and game simulation drills were ~40 minutes in duration and twice as long as skill drills. Given that the individual drills were of different durations, the percentage of time spent in each movement pattern provided the best method of comparing training intensity. Expressing total distance covered in $m \cdot min^{-1}$ indicated that players undertaking conditioning drills covered more than twice the distance (112 $m \cdot min^{-1}$) than simulation and skill drills (range: 50–52 $m \cdot min^{-1}$). Approximately 88–90% of distance covered in simulation and skill drills was completed walking or jogging, whereas in conditioning drills, only 40–63% was completed at these low intensities. In contrast, 33–52% of conditioning drills were covered at striding and sprinting intensities, whereas simulation and skill drills had only 6–8% at these higher intensities. The substantially greater demands of conditioning drills are also reflected by the shorter

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Table 2. Raw data of time–motion variables (mean ± *SD*) for 4 common types of training activities (*n* = number of sessions).*

Workload characteristic	High-intensity conditioning (*n* = 4)	Low-intensity conditioning (*n* = 4)	Simulation (*n* = 11)	Skill (*n* = 9)
Duration (min)	38 ± 10	41 ± 8	43 ± 33	19 ± 13†
Distance				
Walking = 0–2.0 $m \cdot s^{-1}$ (m)	937 ± 376	1,324 ± 487	1,552 ± 1,312	707 ± 466
Jogging = 2.0–3.5 $m \cdot s^{-1}$ (m)	763 ± 217	1,535 ± 1073	416 ± 381†	151 ± 109‡
Running = 3.5–4 $m \cdot s^{-1}$ (m)	462 ± 361	340 ± 300	77 ± 57‡	29 ± 25‡
Striding = 4.0–5.0 $m \cdot s^{-1}$ (m)	1,108 ± 1002	490 ± 451	101 ± 72‡	37 ± 42‡
Sprinting = 5+ $m \cdot s^{-1}$ (m)	1,082 ± 541	1,031 ± 841	86 ± 92‡	23 ± 25‡
Total distance (m)	4,241 ± 1503	4,569 ± 1935	2,231 ± 1,824†	946 ± 616‡
Sprint				
Number (#)	33 ± 10	31 ± 27	6 ± 6‡	2 ± 2‡
Mean sprint distance (m)	31 ± 10	30 ± 32	13 ± 7‡	8 ± 6§
Maximum sprinting speed ($m \cdot s^{-1}$)	7.4 ± 0.0	6.6 ± 0.6‡	4.6 ± 1.0‡	4.3 ± 1.6‡
High intensity efforts				
Number (#)	133 ± 69	102 ± 101	22 ± 17‡	9 ± 11‡
Mean effort duration (s)	4.2 ± 0.2	3.9 ± 1.8	2.9 ± 0.5‡	3.0 ± 0.9‡
Recovery between (s)	4 ± 1	32 ± 39	51 ± 38‡	66 ± 29§
Physiological variables				
Mean heart rate ($b \cdot min^{-1}$)	159 ± 8	144 ± 30	126 ± 11‡	132 ± 10‡
Peak heart rate ($b \cdot min^{-1}$)	191 ± 7	181 ± 11	158 ± 10‡	153 ± 11‡
Peak lactate ($mmol \cdot L^{-1}$)	9.7 ± 1.2	4.7 ± 0.8‡	2.1 ± 0.5‡	

*Magnitudes of difference between high-intensity conditioning drills and other drill types: † = moderate; ‡ = large; and § = very large.

recovery times between high-intensity efforts of high-intensity conditioning drills (4 ± 1 seconds) vs. simulation (51 ± 38 seconds: ES = 1.9 ± 0.4: mean ± 90% confidence limits) and skill (66 ± 29 seconds: ES = 2.1 ± 0.2) drills, respectively. The only clear substantial differences between high- and low-intensity conditioning drills were the higher sprinting speed (7.4 ± 0.0 vs. 6.6 ± 0.6: ES = 1.4 ± 1.2) and the higher lactate values (9.7 ± 1.2 vs. 4.7 ± 0.8: ES = 1.8 ± 0.5) for the high- and low-intensity conditioning drills, respectively.

There were 5–15 times as many sprints and 4–13 times as many high-intensity efforts in conditioning drills vs. the other types of training drills. The distance of efforts in conditioning drills were typically twice as long. Consequently, the greater intensity of these movement differences is reflected in a 9–26% higher mean and 15–25% higher peak heart rate and a 1.2- to 3.6-fold higher peak lactate concentration.

Variability of Time–Motion and Physiological Variables

Variability of training activities was dependent on the type of drill. For low-intensity conditioning drills, the 2 most variable measures were the recovery between high-intensity efforts (%CV = 122%) and the mean sprint distance (%CV = 107%), whereas for high-intensity conditioning drills, the distance covered striding (%CV = 90%) and running (%CV = 78%) were the most variable measures. For simulation drills, the distance covered sprinting (%CV = 107%) and the number of sprints (%CV = 100%) undertaken were the most variable measures. Finally, for skill drills, the most variable measures were striding distance (%CV = 114%) and the number of high-intensity efforts (%CV = 122%). Across all types of conditioning drills, the 2 least variable measures were the peak (%CV range: 4–7%) and mean heart rates (%CV range: 5–21%).

Discussion

This study provides the first quantitative description of the movement demands of various types of training drills undertaken by elite cricketers. Using these data, conditioning coaches can design and improve training drills to more precisely reflect positional match demands. Conditioning drills were designed to enhance the physical fitness of players and elicited substantially greater physical demands than did other training activities. Skill drills were designed to practice isolated technical aspects of game play, whereas simulation drills were designed to practice skills under game-like conditions. Our analysis shows moderate differences in duration and moderate-to-very large differences in intensity and composition of the movement demands between the different types of training drills.

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Each drill classification (i.e., high-intensity conditioning, low-intensity conditioning, skill and simulation drills) incorporated a number of different sessions. The greater the variability of time motion measures within a drill classification, the more diverse the range of sessions. Low-intensity conditioning drills showed the greatest variability, specifically the recovery time between high-intensity efforts. Some conditioning drills emphasized sprint technique, and consequently, longer recovery durations were employed, whereas others targeted improvement of endurance and had shorter recovery periods. Of all drills, high-intensity conditioning drills had the lowest variability in the recovery time between high-intensity efforts; this is not surprising because these drills tended to emphasize development of speed endurance. Simulation and skill drills had a high variability in the number of sprints performed between drills. However, given the small number of sprints involved ($<8 \cdot h^{-1}$), it is not surprising that the variability was high.

Across all drills, heart rate was the least variable measure. Both types of conditioning drills consistently raised the players' heart rates higher than other drills did. However, low-intensity conditioning drills (with more varied recovery times) resulted in greater variability in mean heart rate. In skill and simulation drills consistent but lower heart rates were recorded. Heart rate monitoring especially during simulation drills will enable trainers to redesign drills to closer match or exceed the expected game intensity.

Unsurprisingly, conditioning drills elicited greater physiological demands (higher heart rate and blood-lactate values) and movement demands than other drills. Clearly, the goal of the conditioning coaches was to match or exceed in training the intensity experienced during games. Conditioning sessions were very tightly controlled in their duration and recovery times between high-intensity efforts were strictly enforced. The different goals of individual conditioning sessions dictated the length of recovery periods between consecutive efforts, and this variability is reflected in the moderately high %CV values reported.

Skill and simulation drills were remarkably similar in terms of the intensity of total distance with 50 and 52 $m \cdot min^{-1}$ covered, respectively. However, skill drills were undertaken for a shorter (~50% less) duration than simulation drills and focused on 1 discrete skill a time, whereas simulation drills incorporated all game aspects. Simulation drills had the greatest variability in the duration and in contrast to the tightly controlled duration of conditioning drills were often cut short or extended by the coach in an ad hoc fashion.

In studies of this nature, an interesting analysis is to determine if the players are coached to 'train as they play' (6). Using recently published 1-day and Twenty20 data from the same group of players (although collected over 2 years) (21), the following observations are evident. Fast bowlers are generally accepted in the cricket community to have the greatest physical demands. Fast bowlers in Twenty20 cricket matches (21) had peak heart rates ~181 $b \cdot min^{-1}$; these were equivalent to heart rates in low-intensity conditioning sessions but somewhat lower than heart rates in high-intensity conditioning sessions ~191 $b \cdot min^{-1}$. However, fast bowlers in Twenty20 cricket had peak heart rates greater than both simulation and skill type drills ~158 and ~153 $b \cdot min^{-1}$, respectively.

However, fast bowlers had similar mean heart rates (133 ± 12 $b \cdot min^{-1}$) in Twenty20 cricket as in simulation (126 ± 11 $b \cdot min^{-1}$) and skill drills (132 ± 10 $b \cdot min^{-1}$) but much lower than in conditioning drills (144 ± 30 and 159 ± 8 $b \cdot min^{-1}$). Although Twenty20 fast bowlers maintained their mean heart rate for a longer duration (77 ± 17 minutes), Twenty20 batsmen, with their comparatively shorter duration batting innings (40 ± 14 minutes), had a higher mean heart rate during match play (149 ± 17 $b \cdot min^{-1}$). Therefore, heart rate demands of Twenty20 batting were similar to conditioning drills but higher than simulation or skill drills.

Across 5 positions (fast bowlers, fielders, spin bowlers, wicketkeepers, and batsmen), the total distance covered in games ranged between 2.5 and 4.2, 2.5–3.8, and 2.2–3.8 $km \cdot h^{-1}$ for Twenty20, 1-day, and multiday cricket, respectively (21). In comparison, players covered ~6.9 $km \cdot h^{-1}$ in conditioning drills and 3.0 and 2.9 $km \cdot h^{-1}$ in simulation and skill drills, respectively. These results indicate that conditioning drills provided greater intensity (in terms of hourly distance) than did game activities. Interestingly, simulation and skill drills did not exceed game demands and simulated game demands in some positions. Real-time analysis of GPS data during sessions, particularly in game simulations will enable trainers to identify players that are moving more or less than predetermined targets. Trainers wishing to rectify this situation may move or swap players fielding positions.

Coaches considering modifying training activities based on this analysis should consider incorporating conditioning activities into the simulation drills. Using a short conditioning session immediately before a simulation drill or having conditioning activities interspersed with a simulation drill will increase or even allow the simulation drill to exceed the game demands. Players can then execute their skills under a higher level of physical demand than actually required in a game. Skill drills need to be categorized into those requiring task learning or task proficiency. Although lower physical demands are appropriate for skill learning, at some point, these skills need to be performed at game intensity.

Practical Applications

Undertaking an analysis of the physical demands of cricket training activities is important to ensure training adequately reflects game demands. This information can be used to improve the positional conditioning of particular player types (fast bowlers, batsmen). We showed that commonly employed conditioning drills exceeded game demands, yet skill and more importantly, game simulation drills failed to adequately replicate game demands for all positions. Training drills differ in their type and purpose; nevertheless, coaches

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wanting to accurately simulate game demands need to ensure that physiological demands are not overlooked. Future modification of training activities will ensure a closer matching of game and training demands.

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Chapter 7

Hot / Humid Climate Preparation Strategies

Study 9: Partial heat acclimation in cricketers using a 4-day high intensity cycling protocol.

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Partial Heat Acclimation in Cricketers Using a 4-Day High Intensity Cycling Protocol

Carl J. Petersen, Marc R. Portus, David B. Pyne, Brian T. Dawson, Matthew N. Cramer, and Aaron D. Kellett

Cricketers are often required to play in hot/humid environments with little time for heat adaptation. ***Purpose***: We examined the effect of a short 4-d hot/humid acclimation program on classical physiological indicators of heat acclimation. ***Methods***: Male club cricketers were randomly assigned into heat acclimation (ACC, n = 6) or control (CON, n = 6) groups, and 30 min treadmill trials (10 km/h, approx. 30 ± 1.0°C, approx. 65 ± 6% RH) were conducted at baseline and postacclimation. The ACC group completed four high intensity (30–45 min) acclimation sessions on consecutive days at approx. 30°C and approx. 60% RH using a cycle ergometer. The CON group completed matched cycle training in moderate conditions (approx. 20°C, approx. 60% RH). Physiological measures during each treadmill trial included heart rate; core and skin temperatures; sweat Na^+, K^+ and Cl^- electrolyte concentrations; and sweat rate. ***Results***: After the 4-d intervention, the ACC group had a moderate decrease of –11 (3 to –24 beats/min; mean and 90% CI) in the 30 min heart rate, and moderate to large reductions in electrolyte concentrations: Na^+ –18% (–4 to –31%), K^+ –15% (0 to –27%), Cl^- –22% (–9 to –33%). Both ACC and CON groups had only trivial changes in core and skin temperatures and sweat rate. After the intervention, both groups perceived they were more comfortable exercising in the heat. The 4-d heat intervention had no detrimental effect on performance. ***Conclusions***: Four 30–45 min high intensity cycle sessions in hot/humid conditions elicited partial heat acclimation. For full heat acclimation a more intensive and extensive (and modality-specific) acclimation intervention is needed for cricket players.

Keywords: core temperature, skin temperature, sweat rate, heart rate

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Cricket is a field sport involving intermittent higher velocity running with walking and jogging frequently played in hot and humid environments for extended durations (approx. 6 h/d), over successive (up to five) days. Cricketers' physical performance and motor skills (ie, bowling velocity, line and length) can be compromised in the heat.[1,2] Factors contributing to impaired thermoregulatory function are likely to include adverse environmental conditions (high ambient temperature and relative humidity), cricketers operating at a high intensity (eg, during fast bowling, or sprinting when fielding and batting) and wearing a large amount of protective equipment (batsmen and wicketkeeper) and/or sunscreen which limits evaporative cooling.[3,4] Presumably, episodes of impaired thermoregulatory function are more prevalent in the early part of tours before cricketers are fully heat acclimatized to the local environmental conditions.

It is well established that improved thermal tolerance and endurance capacity occur after repeated exposures (either artificially via heat acclimation; or naturally via heat acclimatization) to a thermally challenging environment.[5] Physiological adaptations associated with heat acclimatization include: a reduced exercising heart rate, a lower core temperature (rectal, tympanic, esophageal), increased sweat rate, a reduced concentration of sweat minerals (sodium, chloride), and an earlier onset of sweating.[6–8] These adaptations enhance fluid balance and distribution and thermoregulatory control; furthermore these adaptations should limit decrements in physical performance while simultaneously improving player comfort levels.

Elite cricketers usually have little time to adapt to local environmental conditions before a tour and often are not fully heat acclimatized before the first few games. An international tour typically comprises several games over several weeks. Traditional heat acclimation leading to improved thermal tolerance and enhanced endurance performance commonly takes up to 10–14 d of repeated heat exposure to achieve 95% of its maximal response (while performing low intensity activity, 50–60% VO_2max).[9] Soldiers wearing normal combat clothing had twofold greater acclimation after 12 compared with 6 d, when acclimating (40°C, relative humidity 30%) by treadmill walking (50% VO_2max speed) for 60 min daily.[10] Importantly for athletes, fitter subjects respond more rapidly to traditional heat acclimation protocols.[11] Nevertheless, a traditional laboratory based heat acclimation protocol involving 7–14 d is often impractical for most elite cricketers.

Recently, a protocol of four high intensity (30–45 min) intermittent exercise sessions (interspersed with recovery days) was used to successfully heat acclimate female hockey players.[12] The athletes' distance run improved 33% during the Loughborough Intermittent Shuttle Test when performed in hot conditions (31°C). These athletes also displayed a lower resting core temperature and reported improved sensations of thermal comfort. We sought to evaluate whether a similar protocol of short duration / high intensity exercise could be used to acclimate cricket players during a short (4 or 5 d) pretour training camp: these camps are commonly used by national teams preparing for competitive games. It is known that with traditional lower intensity acclimation protocols, daily heat exposure is a more effective acclimation strategy compared with intermittent (with recovery days) heat exposure.[13] We modified the high intensity approach used recently in hockey[12] by eliminating the recovery days to create daily heat exposures. This approach could offer promise as an effective and convenient acclimation protocol for cricketers, given their time constraints.

Complicating any heat acclimation protocol is the need of cricket conditioning coaches to limit the running volume of players, particularly fast bowlers. This need stems from research[14] demonstrating that 27% of injuries occurred during practice and training, and most injuries were sustained early in the season when the least cricket is played, with fast bowlers the most susceptible to injury. Fast bowlers missed approximately 16% of potential playing time through injury, where for other positions it was less than 5%. Nearly half of the injuries (49%) were lower limb and when classified by the mechanism of injury, overuse accounted for 17% of all injuries.[14] Microtrauma or overuse injury, results from repeated, abnormal stress (especially on hard surfaces) applied to a tissue by continuous training or training with too little recovery time.[15] Therefore, to limit the volume of running training and potential for overuse injury, it was agreed to utilize cycling exercise for the daily heat exposure in this study. Nevertheless, running testing was performed, as a more cricket-specific exercise modality.

As elite cricketers regularly play in hot and humid conditions, the aim of this study was to quantify the thermoregulatory responses of cricketers to a short 4-d heat acclimation protocol using high intensity cycle exercise. A secondary aim was to assess whether this protocol had any effect on cricket specific repeated running performance. We expect that in comparison with matched training; a short-term heat acclimation protocol will infer superior physiological adaptations and will not be detrimental to cricket specific repeated running performance. For cricketers touring hot and humid countries, the inclusion of an effective heat acclimation program will improve physical preparation and also has the potential to indirectly improve match performance.

Methods

Experimental Approach to the Problem

Utilizing a randomized controlled experimental design, participants completed four high intensity cycling exercise sessions in either hot / humid conditions (approx. 30°C, approx. 61% relative humidity [RH]) or in normal ambient conditions (approx. 20°C, approx. 63% RH). Treadmill running (10 $km \cdot h^{-1}$ for 30 min) in a heat tent (30°C and 65% RH) was conducted at baseline and postintervention to quantify the magnitude of changes in a number of heat acclimation variables. These variables included exercising core and skin temperatures, sweat rate and sweat electrolyte composition. To assess the effect of the acclimation protocol on cricket performance, 15 min after each 30 min treadmill run, a cricket-specific repeated running test was conducted in normal ambient conditions. A schematic of the study design is provided in Figure 1.

Subjects

Senior club level male cricketers (n = 12) volunteered for the study. The cricketers were divided into two groups: an acclimation (ACC, n = 6) and a control (CON, n = 6) group. Age, height, body mass, sum of seven skinfolds and estimated body surface area[16] of the ACC and CON groups were 25.3 ± 4.4, 22.2 ± 3.8 y; 1.83 ± 0.07, 1.82 ± 0.08 m; 81.2 ± 7.3, 85.0 ± 11.0 kg; 71 ± 23, 87 ± 35 mm; 2.03 ±

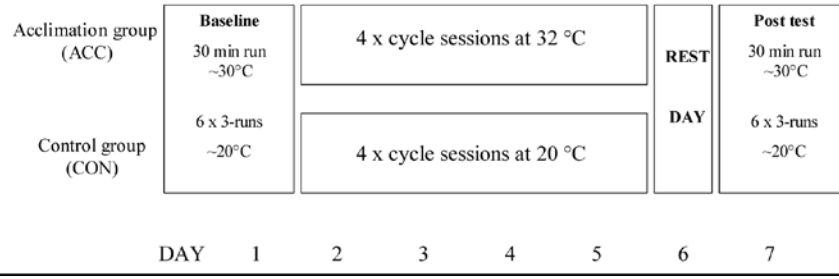


Figure 1 — Schematic diagram of the study design.

0.13, 2.07 ± 0.17 m^2, respectively (mean ± SD). All participants provided written informed consent. The study was approved by the Ethics Committee of the Australian Institute of Sport.

Procedures

Treadmill Testing. All subjects performed two 30 min treadmill runs at 10 $km \cdot h^{-1}$ in a hot and humid heat tent. Dry bulb temperatures and relative humidity (RH) for baseline and posttests averaged 30.1 ± 1.0°C, 64 ± 5%, and 29.8 ± 0.6°C, 64 ± 6%, respectively (mean ± SD). Temperature and humidity was monitored with an environmental monitor (Kestral 3000, Nielsen-Kellerman, Chester, PA, USA) hung 1 m from the ceiling of the tent. Subjects completed baseline and posttrials at the same time of day to control for circadian influences. Subjects were instructed to repeat their previous 24 h diet before each heat test. Four hours before each heat trial, subjects ingested a radiotelemetry pill (CorTemp, HQ Inc, Palmetto, FL, USA) to measure core temperature (T_c).

On reporting to the laboratory, subjects provided a urine sample to assess their hydration status via urine specific gravity (USG) this was measured with a handheld refractometer (PAL-10S, Atago, Japan). Body mass (minimal clothing) and drink bottle mass were then recorded and the CorTemp data logger (HT150001, HQ Inc, Palmetto, FL, USA) used to check data transmission of the ingested radio-telemetry pill. The subjects' left and right forearms were cleaned with an alcohol swab, washed with distilled water and dried. Sweat patches (Tegaderm plus pad 6 × 10 cm transparent film dressing; 3M, Minnesota, USA) were carefully applied horizontally across the upper anterior forearm (participant in the anatomical plane).

Every 5 min during each trial (and 2 min afterward), heart rate (Polar, Kempele, Finland), sternal skin temperature (T_{sk}) (Zeyphr, Bioharness version 2.2.0.10, Auckland, New Zealand), and T_c were recorded. Ratings of thermal sensation (using a 13-point scale from "unbearably cold" to "unbearably hot") and thermal comfort

(using a 5-point scale from "comfortable" to "extremely uncomfortable") were recorded[1] before the start (subjects stood for 5 min in the heat tent before starting each trial), and every 10 min during the 30-min exercise bout.

Two minutes after the 30-min treadmill run, subjects provided a blood sample taken from an earlobe for determination of lactate concentration using an automated analyzer (Lactate Pro, Japan). Sweat rates were estimated from pre- and postexercise body mass measurements after adjusting for fluid intake. Finally, the two sweat patches were carefully removed with tweezers and placed into prelabeled tubes. Sweat samples were analyzed using the ion selective electrode method (Hitachi 911, Roche Diagnostics, Switzerland) to determine the concentration of the electrolytes sodium (Na^+), potassium (K^+) and chloride (Cl^-).

Repeat Run of Three Trials. Fifteen minutes after each treadmill trial, the subjects completed a cricket-specific repeat run of three trials. These trials involved six repeats of the run of three (3 × 17.68 m),[17] starting each repeat on 30 s. Electronic dual beam light-gate timing (Speedlight, Swift performance equipment, NSW, Australia) was employed to measure each run of three repetitions. The total performance time of all six repeats from the run of three trials as well as the time difference between the fastest and slowest repetitions were recorded. A blood lactate sample (Lactate Pro, Japan) was obtained 3 min after the last repetition. These trials were conducted on an outdoor asphalt surface, with pre- and posttrials conducted at approx. 24°C and 48% RH.

Acclimation Sessions. Between baseline and posttesting all subjects completed four consecutive days of intervention (cycling) training using a spin bike (Infiniti, SB250). For group ACC, this intervention involved exercising (heat acclimation) in a heat tent at 30.1 ± 0.8°C and 61 ± 6% RH, while the CON group performed matched training in ambient conditions of 19.9 ± 0.9°C and 63 ± 10% RH (mean difference 10.3 ± 0.4°C, 2 ± 4% RH; mean ± 90% confidence limits). The cycling training involved multiple exercise sets, with each set consisting of eight repeated 20 s maximal efforts interspersed with a 10 s rest. There was a 4 min recovery (low intensity cycling) between each set. In the first and fourth training sessions, four sets (total time 30 min) were performed, whereas six sets (total time 45 min) were performed in the second and third training sessions. Water was drunk ad libitum during all training and testing sessions.

Statistical Analyses

Descriptive data are presented as mean (±SD) and displayed in Table 1. The effectiveness of the heat acclimation for each group was assessed by quantifying the within-individual change scores from baseline to post. In addition, between-group comparisons using the unequal-variances version of the unpaired t-statistic were made on the change scores to assess the effectiveness of the heat acclimation in comparison with the matched training conducted in ambient conditions. Inferential statistics and standardized scores were generated to assess the magnitude of difference between baseline and post. Briefly the criteria for assessing effect sizes (ES) were: <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and >2.0 very large.[18]

Table 1 Changes resulting from 4 d of heat acclimation (ACC) or matched training (CON) in cricketers

	ACC			CON		
Group	**Baseline**	**After**	**Change**	**Baseline**	**After**	**Change**
Treadmill Test						
Prehydration Status—USG	1.014 ± 0.010	1.013 ± 0.008	–0.001 ± 0.009	1.016 ± 0.009	1.021 ± 0.009	0.004 ± 0.010[b]
30 min Fluid (Water) Intake (mL)	112 ± 139	127 ± 145	15 ± 150	66 ± 103	43 ± 67	–23 ± 93
Physiological Responses						
Sweat Conc., Sodium (μmol·L^{-1})	78 ± 12	63 ± 10‡	–14 ± 12	51 ± 14	41 ± 15	–10 ± 15
Sweat Conc., Potassium (μmol·L^{-1})	6.4 ± 0.9	5.4 ± 0.8‡	–0.9 ± 0.9[b]	6.0 ± 1.8	6.0 ± 1.3	0.1 ± 1.6
Sweat Conc., Chloride (μmol·L^{-1})	51.3 ± 9.3	39.8 ± 4.4†	11.5 ± 7.9[a]	32.8 ± 11.8	29.5 ± 11.9	3.3 ± 12.5
Sweat Rate (L·h^{-1})	1.3 ± 0.3	1.2 ± 0.2	–0.1 ± 0.3	1.4 ± 0.3	1.4 ± 0.2	0.0 ± 0.3
Post 2 min Blood Lactate (mmol·L^{-1})	3.4 ± 1.5	2.8 ± 1.4	–0.6 ± 1.5[a]	2.1 ± 0.5	2.1 ± 0.6	–0.1 ± 0.6
Athlete Perception						
Thermal Sensation (Scale 1–13)	10.5 ± 0.6	9.2 ± 1.0†	–1.3 ± 0.8	10.6 ± 0.5	9.5 ± 0.6†	–1.1 ± 0.5
30 min Change in Thermal Sensation	3.5 ± 0.6	2.7 ± 0.8‡	–0.8 ± 0.7[b]	2.6 ± 0.9	2.6 ± 0.8	0.0 ± 0.0
Thermal Comfort (Scale 1–5)	3.1 ± 0.7	2.3 ± 0.5‡	–0.8 ± 0.6	2.9 ± 0.5	2.3 ± 0.5‡	–0.6 ± 0.5
30 min Change in Thermal Comfort	2.1 ± 0.7	1.3 ± 0.5‡	–0.8 ± 0.6	1.8 ± 0.4	1.3 ± 0.5‡	–0.5 ± 0.5
Repeat Run of Three Test						
Total Time (s)	67.87 ± 3.28	67.62 ± 2.81	–0.26 ± 3.22	67.94 ± 2.78	67.82 ± 4.17	–0.12 ± 6.50
Difference Fastest to Slowest Rep (s^{-1})	1.52 ± 0.53	1.24 ± 0.44	–0.29 ± 0.51	1.48 ± 0.70	1.18 ± 0.56	–0.30 ± 1.00
Post Lactate (mmol·L^{-1})	13.6 ± 2.3	13.5 ± 1.9	–0.2 ± 2.2	12.9 ± 2.2	11.3 ± 1.8	–1.7 ± 3.2

Note. +Small, ‡moderate, and †large magnitudes of difference between baseline and posttesting within group, and [a]small and [b]medium magnitudes of difference in the between-group changes scores.

Results

Intervention Training Sessions

During the four cycling training sessions the heart rate (postset) and blood lactate (postsession) measures were 174 ± 6 beats·min^{-1} and 10.5 ± 2.8 mmol·L^{-1} for the ACC group, and 170 ± 12 beats·min^{-1} and 11.3 ± 3.2 mmol·L^{-1} for the CON group. The interventions were comparable in terms of blood lactate (ie, no substantial difference) but a small difference existed in heart rate (lower in CON, ES = 0.48 ± 0.21).

Pretest Hydration

There were only trivial within-group changes in USG measurements for baseline and posttests respectively. However, there was a moderate (ES = 0.63 ± 0.70) between group difference in hydration change scores, with the CON group becoming more dehydrated (Table 1).

Treadmill Tests

Figure 2 shows the exercising heart rate, core and skin temperatures during the treadmill tests. From baseline to posttesting there was a moderate decrease (11 beats·min^{-1}, ES = –0.83 ± 1.01) of the 30 min heart rate for the ACC group. In addition, from baseline to posttest, both the ACC and CON groups had a moderate decrease (19 beats·min^{-1}, ES = –1.18 ± 0.86; 11 beats·min^{-1}, ES = –0.85 ± 0.99) in the recovery heart rate 2 min posttrial, but the magnitude of change in ACC was not greater than in CON. Between-group changes in posttrial exercising heart rates were trivial. For T_c and T_{sk} temperatures, all changes between baseline and posttest were trivial in both groups. Furthermore, the magnitude of the between group changes in both T_c and T_{sk} were unclear.

The ACC group exhibited substantial reductions in sweat Na^+, K^+ and Cl^- electrolyte concentrations, and substantial improvements in all measures of thermal sensation and comfort, after 4 d of heat training. In comparison, the CON group had only substantial improvements in measures of thermal sensation and comfort. The ACC group had small (ES: 0.33 ± 0.51) and moderately (ES: 0.88 ± 0.82) greater reductions in chloride and potassium respectively, (but not sodium) in comparison with CON. Table 1 shows the physiological responses and participant's perceptions from baseline and posttest trials.

Repeat Run of Three Trials

There were only trivial changes in all performance (total time, difference between the fastest and slowest repetition) and blood lactate measures of the repeat run of three trials for both ACC and CON groups (Table 1).

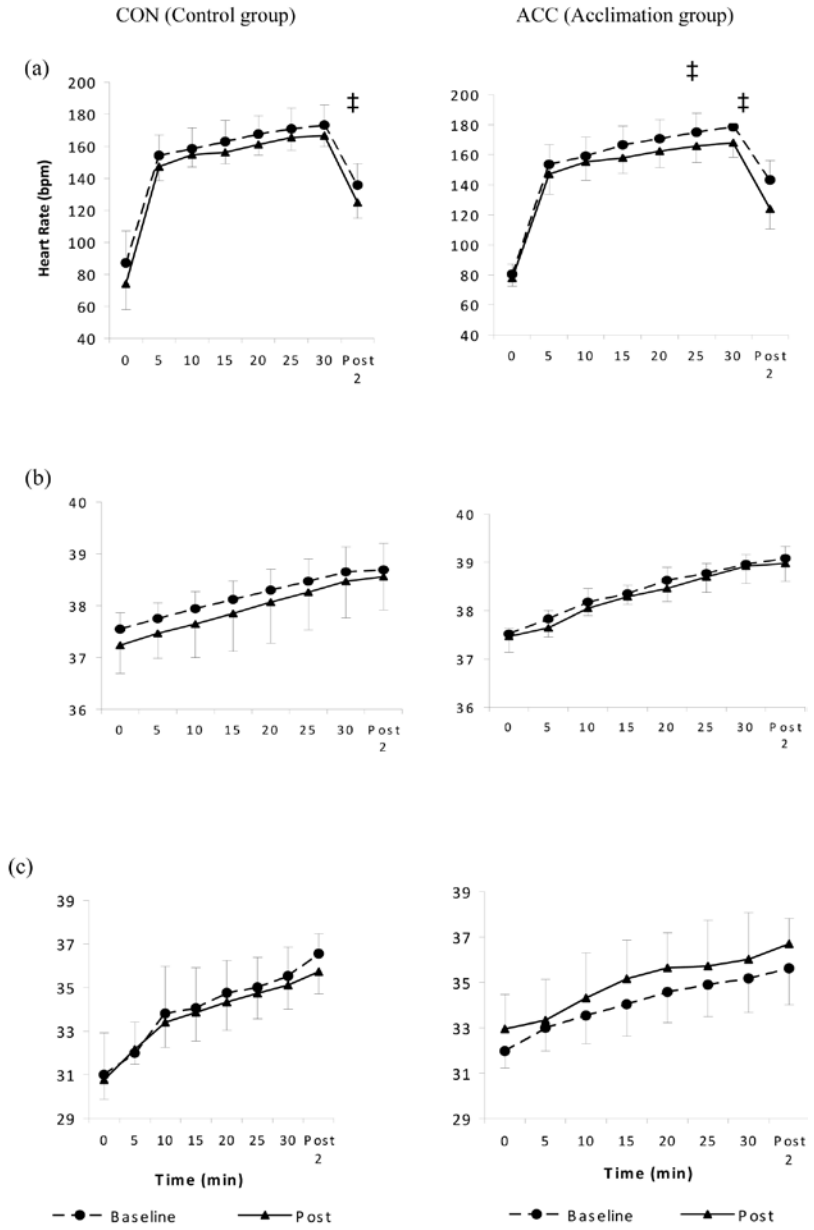


Figure 2 — CON (left column) and ACC (right column) group responses to 4 d of high intensity acclimation. *Note.* Mean (±SD) (a) heart rate, (b) core temperature (T_c), and (c) skin (sternal) temperature (T_{sk}) values recorded in the 30 min treadmill runs (approx. 30°C, 64% RH) for the CON (left column) and ACC group (right column). Within group, +small, ‡moderate, and †large magnitudes of difference between baseline and posttest. There were no differences between groups.

Discussion

The main finding of this study was that 4 d of heat acclimation via high intensity cycle exercise was sufficient to elicit partial thermoregulatory adaptations in club cricketers without harming sport-specific repeat sprint exercise performance. The 4-d heat acclimation protocol elicited substantial decreases in sweat electrolyte concentration and 30 min exercising heart rate, while a control group showed only trivial changes in these variables. Both groups had improved perceptions of thermal sensation and comfort while exercising in the heat. However, there were no substantial changes in other physiological variables (increased sweat rate, decreased core temperature) indicative of full heat acclimation. A longer duration or more exercise-specific acclimation protocol may be required to obtain a greater acclimation response in these subjects.

A key issue is the degree of full acclimation that can be achieved by athletes/cricket players in a short time frame of a few days. From traditional heat acclimation research (involving daily 50–70 min of running or cycling at 50–60% VO_2max) it is known that (1) the process of adaptation to exercise in the heat begins within a few days; (2) full adaptation takes 7–14 d for most individuals, and (3) different systems of the human body adapt at varying rates to successive days of heat exposure.[19] Decreased heart rate and plasma volume expansion takes 3–6 d to occur,[19,20] decreases in sweat Na^+ and Cl^- concentrations take 5–10 d, and increased sweat rate, sensitivity and increased skin vasodilation take 7–14 d for 95% of the adaptation to occur.[21] The sudomotor modifications potentially represent the most potent adaptive response.[5] Plasma volume expansion resulting from increased plasma protein and sodium chloride retention ranged from 3 to 27% and was accompanied by a 15–25% decrease in heart rate during the first 5 d of heat acclimation.[21] In the present study the ACC group showed a moderate 6% reduction in 30 min heart rate after 4 d of acclimation, indicating there was still scope for further or additional improvement. After complete acclimation, sodium concentrations in sweat are reduced by approximately 50% for any specific sweat rate.[22] We observed sweat sodium concentrations were reduced by 18% in the ACC group, indicating there was scope to further reduce sweat electrolyte concentration. The adaptations of increased sweat rate and sweat sensitivity, and a reduced core temperature threshold for sweating onset, combine to produce up to a twofold increase in sweat rate (increasing from 1.5 to 3.0 $L \cdot h^{-1}$).[4] In this study, there was no increase in sweat rate in the ACC group. The 4-d high intensity heat acclimation protocol used here appears to be too short to make substantial changes to the sweat rate.

Cricketers are involved in a running sport, yet cricket conditioning coaches and physiotherapists are often cautious with regard to the running volume that cricketers undertake. The heat adaptation used here involved a nonspecific exercise (4 d of cycling), while the cricketers were tested in a running protocol (specific to cricket). Greater adaptations might have occurred here with a running acclimation protocol. However, undertaking a running-based acclimation protocol could expose cricketers to a higher injury risk if they are not accustomed to the volume of running required. It is well accepted that overuse injuries are often a result of a rapid increase in training volume or excessive training volume on hard training surfaces.[15]

The cricketers involved in this study were of a lesser standard (club cricketers) and presumably a lower fitness level than elite (international) cricketers. For example, during the same 30 min treadmill test a group of 14 trained elite cricketers

in our laboratory had a moderately lower peak heart rate (167 ± 10 vs 176 ± 11 beats·min^{-1}) compared with the cricketers in the present study (C.J. Petersen, Australian Institute of Sport, unpublished data). One indicator of improving fitness is that the heart rate during the immediate postexercise recovery period decreases faster (returning toward resting level). Both groups improved their 2 min recovery heart rate after the 30 min run by 19 and 11 beats·min^{-1} (ACC and CON groups, respectively). Therefore, we tentatively interpret these findings as that at least half of this moderate 19 beats·min^{-1} improvement in the ACC group could be indicative of an increase in fitness (the cricketers were in their preseason preparation) whereas the remainder of the improvement is likely from improved heat adaptation. While this protocol did not improve cricket-specific repeated high intensity running, it also did not compromise this performance. Therefore, a more aggressive approach (greater number or duration of heat adaptation sessions) could be trialed with club cricketers; however, it may be more effective to use a more modality-specific (running) intervention if the players can tolerate the increased volume of running.

Future work with cricketers undertaking high intensity acclimation should investigate the time course of the plateau effect of the various acclimation/acclimatization changes using a longer experimental protocol. A recent recommendation indicated the heat acclimation of individuals in the general population using a short-term protocol (traditional approach, 90 min per day for 5 d, controlled hyperthermia, and limited to a peak core temperature of 38.5°C) should not be completed more than 1 wk before their relocation to a heat stressful environment. One additional heat exposure should be used for each 5 d away from significant heat exposure.[23] There is a need for similar recommendations for athletes especially when undergoing high intensity exercise heat acclimation protocols before major competition.

Practical Implications

With senior club cricketers, 4 d of high intensity cycling exercise in the heat was sufficient to produce moderate to large decreases in sweat electrolyte concentrations, and moderate improvements in exercising heart rate, thermal sensation and comfort. However, improvements in thermal sensation and comfort can also be gained using the same protocol in ambient conditions. Substantial changes in other key heat acclimation indicators such as core temperature and sweat rate require more than four sessions in the heat.

While it could be argued that physiological adaptations are fast tracked using this 4-d heat acclimation protocol, adaptations will still be occurring upon arriving in the targeted hot and humid environment. Therefore, we recommend a more intensive and/or extensive (and exercise-specific) acclimation protocol be employed to elicit full heat acclimation in cricketers.

Acknowledgments

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Chapter 7

Hot / Humid Climate Preparation Strategies

Study 10: Heat acclimation versus acclimatisation of elite cricketers.

In preparation for submission to New Zealand Journal of Sports Medicine

Abstract

Physical preparation for elite cricketers competing in hot and humid conditions usually involves pre-departure (artificial) acclimation or earlier arrival to facilitate acclimatisation. We examined classical physiological indicators of heat adaptation to quantify the effectiveness of these two methods. Fourteen elite Australian cricketers (travelling to India) were allocated into a Brisbane (Australia) based acclimation group (BRIS, n=5) and a Chennai (India) based acclimatisation group (CHEN, n=9). Thirty minute 10 $km \cdot hr^{-1}$ treadmill run tests were conducted at baseline in Australia (~30°C, ~65% RH) and post-intervention in India (~30°C, ~70% RH). Between baseline and post-testing, both groups performed four matched heat training sessions (30-45 min) of repeated sprints on a cycle ergometer on consecutive days. The BRIS group completed sessions in a heat tent (~33°C, 70% RH), while the CHEN group performed sessions under Indian ambient conditions (~30°C, 65% RH). Other cricket training (~9 hr) was matched for content and duration. Both groups travelled 18–24 hours from Australia to India (via Dubai). The CHEN group travelled immediately following baseline testing; the BRIS group travelled immediately following their last acclimation session (Post testing, 24–36 hours after arriving). The CHEN group had moderate to large decreases in sodium, potassium and chloride sweat electrolyte concentrations of 23 – 46% during treadmill exercise, whereas the BRIS group only had a moderate 17% reduction in sweat chloride. The magnitude of all other indicators of heat adaptation were similar between groups. The 4-day heat intervention had no detrimental effect on performance. In conclusion, 4 days of acclimatisation provided only slightly superior effects to a 4 day heat acclimation program. A longer and more intensive heat acclimation strategy is recommended for elite cricketers.

Keywords: core temperature; skin temperature; sweat rate; heart rate

Introduction

Two methods employed during the physical preparation of cricketers who must compete in hot and humid environments are heat acclimation and heat acclimatisation. Acclimation is the process where the body adapts by exercising in an artificial environment that mimics the target environment. In contrast, acclimatisation refers to the body's natural process of adaptation through exposure to the actual target environment. Elite cricketers are often required to compete in environmental conditions more severe than that to which they are currently adapted. Additionally, the increasingly congested international game schedule often dictates that early arrival to acclimatise is not possible. Therefore, it is important to quantify the extent of adaptation that is possible with acclimation and acclimatisation protocols to improve the preparation of elite cricketers playing in environmentally challenging conditions.

In designing an acclimation protocol a number of logistical factors must be considered. In practice, a training or conditioning room needs to be maintained at a set target temperature and humidity; a combination of a tent with electric heaters and a water bath provides a cost effective method to do this. Secondly, acclimation is more effective when athletes actively exercise in the heat (18), and therefore the exercise of choice must be performed within the physical constraints of the heated area (tent). Employing a heat acclimation protocol within a busy team schedule (around other training) dictates that the protocol needs to be time efficient, and therefore it is desirable to have multiple athletes acclimating at the same time. For this reason, easy to manage cycle ergometers are generally preferred to cumbersome portable treadmills. Finally, to avoid overuse injuries the training load (intensity, duration and frequency) must be managed so that athletes do not experience a sudden increase or an excessive total training volume (11).

Cricketers are involved in a highly intermittent sport featuring multiple short sprints with a substantial base of low-intensity activity (10). However, the management of overuse injury concerns (particularly lower limb) limits the prescription of running activity by cricket conditioning coaches. In particular, cricket fast bowlers have the highest prevalence of injury (9,14) and are generally on a controlled running program outside game activities to alleviate the strain on their lower limbs. Consequently, cycle exercise is often practically a better option for most elite cricketers undertaking heat acclimation.

The aim of this study was to compare the adaptation responses of elite Australian cricketers to short 4 day artificial (acclimating) or natural (acclimatising) training in the heat prior to an international tournament in India. This information will enable modification and refinement of acclimation or acclimatisation strategies for cricketers competing in hot and humid environments.

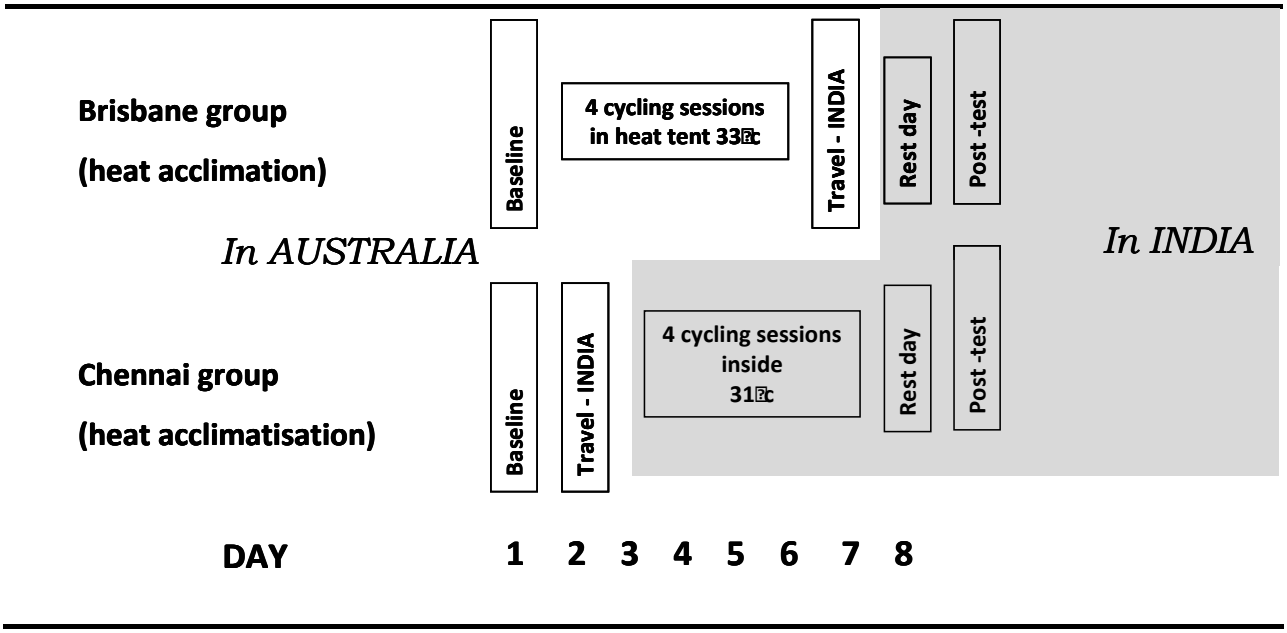
Methods

Experimental approach to the problem

Utilizing a randomized open trial experimental design, participants either completed four days of heat acclimation (in Australia) or acclimatisation (in India). Both groups completed four high intensity cycling exercise sessions in hot / humid conditions (30-33°C, 65-70% relative humidity (RH)). All other training (~9 hr) was matched for content and duration and performed in normal ambient conditions (Australia; 22 ± 2°C, 48 ± 7% RH; India; 33 ± 2°C, 69 ± 6% RH: mean ± 90% confidence limits). Treadmill running (10km.hr^{-1} for 30 min) in a heat tent (30°C and 65-70% RH) was conducted at baseline (in Australia) and post

intervention (in India) to quantify the magnitude of change in a number of variables indicative of heat acclimation. These variables included the classical thermoregulatory variables of exercising core and skin temperatures, sweat rate and sweat electrolyte composition. To assess the effect of the training acclimation protocol on cricket performance, a cricket-specific repeated running test was conducted in normal ambient conditions at least 15 min after each 30 min treadmill run. A schematic of the study design is provided in Figure 1.

Fig. 1. Schematic of the study design



Subjects

Elite male cricketers (n=14) from the Cricket Australia Centre of Excellence volunteered for the study. Players were divided into a Brisbane, Australia based acclimation (BRIS, n=5) and a Chennai, India based acclimatisation (CHEN, n=9) group matched on physiological and skill attributes. Age, height, body mass, sum of seven skinfolds, estimated body surface area (5) and Yo-Yo Level 1 intermittent recovery test performance of the BRIS and CHEN groups were similar between them: 22.0 ± 3.0, and 23.7 ± 7.7 years; 1.88 ± 0.10 and 1.86 ± 0.06 m;

87.3 ± 9.3 and 85.1 ± 6.8 kg; 63 ± 12 and 68 ± 15 mm, 2.14 ± 0.16, 2.11 ± 0.08 m^2 and 2000 ± 416 and 2056 ± 649 m, respectively (mean ± SD). All participants provided written informed consent and the study was approved by the Ethics Committee of the Australian Institute of Sport.

Procedures

Baseline and Post-Testing

Treadmill test

All participants performed a 30 min treadmill run at 10 $km.hr^{-1}$ in the heat and humidity tent on two occasions (Baseline and Post test). Baseline testing was conducted in Brisbane, Australia (30.8 ± 0.5°C, 66 ± 3% RH; mean ± SD) while post-testing was conducted in Bangalore, India (30.2 ± 0.5°C, 72 ± 3% RH). The internal heat tent humidity was 6% higher for the post-testing due to the higher Indian ambient humidity. The same electric heaters and humidity bath were used to control heat and humidity in baseline and post-testing. The tents environmental characteristics were monitored with a Kestral 3000 environmental monitor (Nielsen-Kellerman, Chester PA, USA) hung 1 m from the tent ceiling.

Participants completed baseline and post-testing at the same time of day to control for circadian variation. A minimum of four hours prior to each treadmill trial, participants ingested a radio-telemetry pill (CorTemp™, HQ Inc, Palmetto, FL, USA) to enable the recording of core temperature (T_c) during the trial. The CorTemp™ data logger (HT150001, HQInc, Palmetto, FL, USA) was used to obtain T_c readings from the radio-telemetry pill.

Prior to the treadmill run, participants provided a urine sample to assess their hydration status via urine specific gravity (USG). Body mass (minimal clothing) and drink bottle mass were recorded and sweat patches (Tegaderm plus pad 6 x 10cm transparent film dressing; 3M, Minnesota, USA) were applied horizontally across the superior aspect of the anterior forearms. Prior to sweat patch application, the forearms were cleaned with an alcohol swab, washed with distilled water and dried with a sterile tissue.

Heart rate (Polar, Kempele, Finland), skin temperature (T_{sk}) (Zeyphr, Bioharness Version 2.2.0.10, Auckland, New Zealand) from the sternum, and T_c were constantly monitored throughout each trial and recorded every 5 minutes. Ratings of thermal sensation (using a 13-point scale from "Unbearably cold" to "Unbearably Hot") and thermal comfort (using a 5-point scale from "Comfortable" to "Extremely Uncomfortable") (4) were recorded at the start, every 10 minutes during, and upon completion of the 30-minute treadmill run. After completing the treadmill run, participants had a 5µl blood sample taken from the earlobe for immediate determination of lactate using an automatic analyser (Lactate Pro, Japan). Measurements of T_{sk}, T_c and heart rate were also recorded two minutes after completion of the run. Sweat rates were estimated from pre-exercise and post-exercise body mass measurements after adjusting for fluid intake. Sweat patches were carefully removed with tweezers and placed into pre-labelled tubes. The tubes were centrifuged at 5000 $rev.s^{-1}$ for four minutes. Sweat was then analysed using the ion selective electrode method (Hitachi 911, Roche Diagnostics, Switzerland) to determine the sweat composition of the electrolytes sodium (Na^+), potassium (K^+) and chloride (Cl^-).

Repeat run of three test

On the same days as the treadmill testing, cricket specific run-of-three tests were also performed. The run-of-three test involved running six repeats of three runs (3 x 17.68 m) (7), starting each repeat every 30 seconds. Electronic dual beam light-gate timing (Speedlight, Swift Performance Equipment, Australia) measured each run-of-three. Because the test was performed on different surfaces in Australia (basketball court, 21◦C and 54% RH and outdoor synthetic 23◦C and 47% RH) and India (indoor cricket wicket, 28◦C and 55% RH) total performance time was not compared. Instead, the difference between the fastest and slowest repetition was used as a performance measure. Recovery heart rate was monitored every 30 seconds during the first two minutes after completion of the last repetition. The % heart rate recovery was calculated as the percentage of the two minute recovery that occurred within the first minute.

Heat Training Intervention

Acclimation training sessions

Between baseline and post-tests participants undertook four consecutive days of acclimation cycling training sessions. Group CHEN travelled to Chennai (India) and undertook matched exercise sessions indoors with no air-conditioning (30.3 ± 3.1°C, 65.3 ± 4.1% RH). The BRIS group performed their acclimation training sessions in a heat tent in Brisbane (32.8 ± 1.3°C, 69.0 ± 2.0% RH) prior to travelling to India (Bangalore). Both groups undertook 18–24 hours travelling to India, while the CHEN group also flew ~1 hour from Chennai to Bangalore for post-testing.

In brief, the acclimation training sessions involved multiple cycling sets. Each cycle set required participants to perform eight repeated 20s maximal efforts interspersed with 10

second rest periods. Each set was interspersed with a four minute recovery (light cycle) period (16). In the first and fourth training sessions, four sets (30 minutes) were performed, whereas six sets (45 minutes) were performed in the second and third training sessions. Water was drunk ad libitum during all training and testing sessions. Figure 1 illustrates the study design.

Other training sessions

All cricket-specific training sessions were replicated in terms of session content, drill design and (where possible) duration (Table 1).

Table 1. Cricket-specific training sessions for the Brisbane (BRIS) and Chennai (CHEN) groups undertaking heat acclimation and acclimatisation training.

		BRIS Group				CHEN Group			
Day	Session	Temp (◦C)	Humidity (%)	RPE (#)	Duration (mins)	Temp (◦C)	Humidity (%)	RPE (#)	Duration (min)
1	Fielding	23	47	6.5 ± 0.8	82	32	65	4.5 ± 1.8	87
1	Weights	19	53	4.0 ± 1.0	40	33	60	4.2 ± 2.0	40
2	Skills / centre	21	65	4.2 ± 1.5	137	34	65	4.7 ± 2.3	140
3	Fielding and skills	28	43	3.0 ± 1.0	107	38	70	4.3 ± 2.1	120
4	Centre wicket	23	32	4.4 ± 0.9	122	29	85	4.3 ± 0.6	120
4	Weights	19	45	4.0 ± 1.0	45	30	70	4.5 ± 0.5	45

RPE scale: 1= No exertion at all, 3= very light, 5 = moderate, 7 = hard, 10 = maximal exertion

Statistical analyses

Descriptive statistics were expressed as mean ± SD, while effects were expressed as mean ± 90% CL for effects. The effectiveness of the heat acclimation was assessed by quantifying the within- individual change scores from baseline to post-test for each group. A standardized change score (effect size statistic) was used to assess the magnitude of difference between baseline and post-test. Briefly, the criteria for assessing the effect size (ES) were: <0.2 trivial,

0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, and >2.0 very large (6). A standardized difference score was generated on the post minus baseline change scores to establish the superiority of a particular approach.

Results

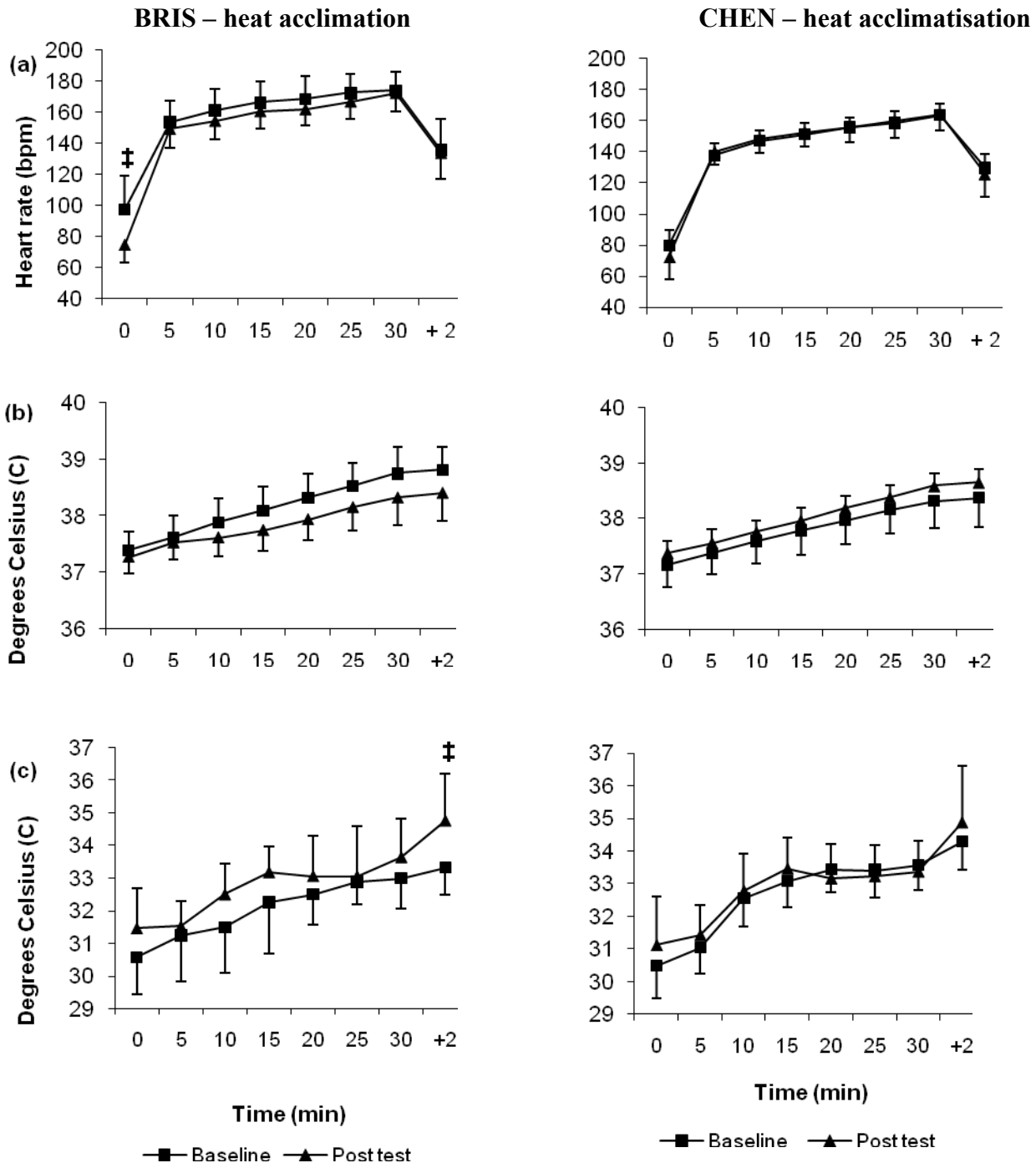
Acclimation training sessions

The mean heart rate and blood lactate measures for the four cycling exercise sessions were 169 ± 12 beats.min^{-1}, 4.7 ± 1.9 mmol.l^{-1} and 179 ± 8 beats.min^{-1}, 8.4 ± 3.2 mmol.l^{-1} (mean ± SD) for the BRIS and CHEN groups respectively.

Treadmill tests

In the post-test compared to the baseline test both groups had moderate to large changes (improvements) in their pre-test hydration status (as evidenced by the USG measurements). The CHEN group achieved a substantial increase in sweat rate and reduction in concentration of all three sweat electrolytes. In comparison, the BRIS group only had a substantial reduction in chloride concentration. Table 2 shows the physiological responses and participant's perceptions from the baseline and post-testing. In the treadmill tests mean heart rate increased by 87 ± 8 and 88 ± 4 beat.min^{-1} (mean change ±90% confidence limits) over the 30 min in the BRIS and CHEN groups respectively. All comparisons of baseline to post heart rate changes were trivial except the pre heart rate of the BRIS group; moderate 22 beat.min^{-1} decrease (ES= -1.08 ± 1.05). Figure 2 shows the exercising heart rate, core and skin temperatures during the treadmill tests. In the BRIS group, there is a trend (not substantial) of a lower heart rate and core temperature but increased skin temperature in the post test. In comparison, the CHEN group had a trend (not substantial) of a similar heart rate and skin temperature, but an increased core temperature in the post test.

Fig. 2. Heat adaptation improvements in the BRIS (left column) and CHEN (right column) groups after 4 days of acclimation and acclimatisation respectively (during 30 min baseline and post treadmill tests). There were no substantial differences between groups.



Mean (±SD) (a) heart rate, (b) core temperature (T_c), and (c) skin temperature (T_{sk}) values recorded during the 30 min treadmill runs (Baseline: ~31°C, 66% RH; Post test: ~30°C, 72% RH). Within group, + Small ‡ moderate and † large magnitude of difference between baseline and post test.

Repeat run of three tests

Comparing baseline to post testing, the CHEN group had a moderately lower peak recovery heart rate (6 beats.min^{-1}; ES= 1.17 ± 0.89). There were no other substantial differences in the changes from baseline to post-testing of the run-of-three test (Table 2).

Table 2. Heat adaptation changes resulting from 4-days of heat acclimation (BRIS) or acclimatisation (CHEN). The only substantial difference between groups was the sweat concentration of potassium.

Group	BRIS			CHEN		
	Baseline	Post	Change	Baseline	Post	Change
Treadmill Test						
Pre hydration status - USG	1.023 ± 0.003	1.012 ± 0.006†	-0.011 ± 0.004	1.020 ± 0.008	1.011 ± 0.005‡	-0.009 ± 0.008
30-min fluid (water) intake (ml)	400 ± 310	350 ± 400	-0.51 ± 508	330 ± 70	130 ± 150	-199 ± 128
Physiological responses						
Sweat conc. – Sodium ($umol \cdot l^{-1}$)	79.6 ± 10.9	70.4 ± 13.4	-9 ± 15	79.8 ± 22.8	61.1 ± 12.0‡	-19 ± 28
Sweat conc. – Potassium ($umol \cdot l^{-1}$)	8.0 ± 2.2	7.3 ± 2.7	-1 ± 3	9.6 ± 4.0	5.5 ± 0.9†	-4 ± 4‡
Sweat conc. – Chloride ($umol \cdot l^{-1}$)	60.0 ± 9.3	49.7 ± 11.7‡	-10 ± 14	58.0 ± 21.1	42.7 ± 9.4‡	-15 ± 25
Sweat rate ($L \cdot hr^{-1}$)	1.5 ± 0.3	1.8 ± 0.5	0.3 ± 0.4	1.2 ± 0.2	1.5 ± 0.5‡	0.3 ± 0.3
Post 2-min blood lactate ($mmol \cdot L^{-1}$)	2.0 ± 0.8	2.4 ± 1.0	0.4 ± 0.3	1.3 ± 0.3	1.9 ± 0.7‡	0.6 ± 0.7
Athlete perception						
Thermal sensation (Scale 1-13)	10.0 ± 1.0	9.4 ± 1.3	-0.6 ± 0.5	10.2 ± 1.0	9.9 ± 1.0	-0.2 ± 1.2
30 min change in thermal sensation	2.8 ± 0.8	2.4 ± 1.3	-0.4 ± 0.9	3.4 ± 1.4	3.4 ± 1.2	0.0 ± 1.6
Thermal comfort (Scale 1-5)	3.1 ± 1.0	2.8 ± 1.1	-0.3 ± 0.8	2.8 ± 1.2	2.6 ± 0.9	-0.2 ± 0.9
30 min change in thermal comfort	2.1 ± 1.0	1.8 ± 1.1	-0.3 ± 0.8	1.7 ± 1.0	1.6 ± 0.9	-0.1 ± 0.8
Repeat run of three test						
Difference fastest to slowest rep (s^{-1})	1.01 ± 0.15	1.00 ± 0.12	-0.01 ± 0.22	1.05 ± 0.28	0.92 ± 0.16	0.35 ± 0.82
Peak heart rate ($beats \cdot min^{-1}$)	184 ± 8	182 ± 12	-2 ± 6	182 ± 3	176 ± 7‡	-7 ± 3
2 min heart rate recovery ($beats \cdot min^{-1}$)	37 ± 6	40 ± 7	2 ± 7	49 ± 5	49 ± 8	0 ± 9
Heart rate recovery speed (%)	45 ± 10	48 ± 11	2 ± 10	48 ± 13	52 ± 12	4 ± 12

+ Small ‡ moderate and † large magnitude of difference between baseline and post-testing within group, and between group change scores

Discussion

The main finding of the present study was that four days of acclimatisation by cricket players in India conferred only slightly superior adaptations to a matched four day heat acclimation program performed in Australia. However, both approaches failed to elicit substantial improvements in all of the classical physiological measures of heat adaptation. While the acclimatisation group substantially reduced the concentration of all three sweat electrolytes, other key indicators of heat adaptation (decreased core temperature, reduced exercising heart rate, and increased sweat rate) showed little response in either group. We interpret this finding as heat acclimation or acclimatisation requires a greater or longer stimulus to ensure a more complete adaptation.

Exercise modality specificity (running as opposed to cycling) for heat adaptation training by athletes (including cricketers) also needs to be considered. A similar study using four short heat acclimation sessions of high intensity running (in this case modality-specific exercise) reported that the acclimation (30ºc, 27% RH) group showed a greater reduction in core temperature responses than a matched training (18ºC, 41% RH) group (15). However, similar to our findings, Sunderland et al. (15) also reported that both the acclimation and matched training groups decreased their exercising heart rates by a similar magnitude in the heat. These contrasting results indicate that modality specificity should be considered when designing a more effective heat acclimation protocol.

The cumulative effects of the four day heat training protocol were not detrimental to cricket-specific run-of-three performance. Therefore, elite cricketers could be expected to handle an even greater short term load to acclimatise to heat without compromising cricketing performance. This question should be assessed on an individual basis, taking into account each player's recent fitness training history. Future refinement of the

acclimation protocol should consider increasing the number of days, and/or the length of the sessions. Physiological adaptations occur at varying rates during acclimatisation, and can take up to 14 days for 95% of the physiological adaptations to occur (3). Traditionally, more than seven days of long duration (~60 min) continuous exercise of a low to moderate intensity (50–60% VO_2max) is used to induce acclimation in athletes (1). The rationale for this study has come from research showing high intensity intermittent exercise provides a greater thermal strain than continuous exercise, and a potentially more powerful stimulus for acclimation (8). However, research findings must be implemented within the imposed practicalities and time constraints of elite cricketers' schedules; Cricket Australia pre-departure training camps are generally only 4-5 days long. The choice of a more specific (running) exercise modality for the acclimation sessions deserves consideration (17), but will need to be balanced against a possible heightened risk of overuse injury.

It is important to note all participants conducted their post treadmill test in slightly more adverse environmental (6% more humid) conditions. This difference did not offer an advantage to either group, but should be considered when comparing thermoregulatory measures between baseline and post-testing. Despite this, we observed the expected trend in physiological measures of heat adaptation. Similar ratings of perceived thermal comfort levels indicate participants found a slightly harsher environment comparable to the initial treadmill test environment and not more stressful. The same logic can be applied to heart rate and core temperature responses. However, there is still scope for additional improvement in the key indicators of heat adaptation. In the present study, sweat sodium concentrations were reduced by 12 and 23%, and sweat rate increased by 20 and 26% in the BRIS and CHEN groups, respectively. After complete acclimation, sodium concentrations in sweat are reduced by approximately 50% for any specific sweat rate (12). Steady state

sweat rate can increase two-fold (18) and a 15-25% decrease in exercising heart rate has been shown to occur in the first 5 days of heat acclimation (2).

The main difference between the two groups was the more intensive training undertaken by the group that travelled to India earlier (CHEN group). The increased intensity was indicated by the 10 beats.min^{-1} greater peak heart rate and 3.7 mmol.l^{-1} greater lactate measurements taken after the conditioning sessions. There are several possible explanations for this difference in training intensity. First, the CHEN group may have experienced the 'training camp effect', and produced a greater intensity of effort from being outside their normal training environment. These players were challenged from a skill perspective by training against motivated fast bowlers they had not previously encountered, while at the same time they were also confronted with the new environment, food, air quality and intensive training. It has been suggested that it takes two weeks of controlled training to overcome the training camp effect in collegiate-level athletes (13). In contrast, the BRIS group had been training in the same environment for the previous 14 weeks. Secondly, the higher heart rates and lactate measures of the CHEN group may relate to the more challenging environmental conditions of Chennai during the training day. Both groups were encouraged to give maximum effort during the cycle exercise sessions. However, without power measurements, any differences in intensity between the groups could not be identified.

The CHEN groups indoor training sessions (the non air-conditioned gym had big open windows) were conducted within 2◦C and 5% RH of the BRIS group. Moreover, the ~9 hr of outdoor net / fielding and gym sessions in Chennai were performed in conditions that were 6-14◦C hotter and up to 54% more humid than the matched training performed by the BRIS group. Despite the greater thermal stimulus experienced by the CHEN group, 4-days

of heat acclimatisation provided only slightly superior results than a 4-day heat acclimation program.

Practical applications

Practitioners need to be aware of this knowledge:

- Four days of high intensity cycling exercise in the heat is not sufficient to elicit small to moderate changes in cricketers in all of the classical indicators of heat adaptation. Substantial changes in core temperature, heart rate, sweat rate and perceived exertion in elite cricketers require more than four sessions.
- Moderate to large changes in sweat electrolyte concentrations can occur in the first few days of acclimatisation in elite cricketers.
- Physiological adaptations can be fast tracked with prior heat acclimation work before embarking on a sub-continental tour; however only partial thermoregulatory adaptations can be expected after four days.
- Exercise performance (run-a-three repeat effort) test was maintained but not improved after both heat acclimation and heat acclimatisation protocols.

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Chapter 8

Discussion

The relatively limited (compared to other sports) body of peer reviewed literature describing the physical demands of cricket has been expanded by the papers comprising this thesis. Collectively these papers provide a valuable resource for conditioning practitioners. The data can be utilised in the design of annual conditioning plans and also provides conditioning practitioners with the physiological effect of various cricket specific training drills. Furthermore, practitioners working with teams (international or professional domestic) travelling to international tournaments (Champions trophy) will benefit from the heat adaption studies. When using a short duration acclimation or acclimatization strategy, the heat study data quantifies the extent that elite cricketers adapt (indicated by key physiological measures) by modifying the time-course of the intervention practitioners are able to enhance the expected adaptation of the athletes.

The considerable statistical reporting within the sport of cricket was utilised in the first two studies of this thesis to investigate team indicators of successful performance. This novel performance analysis approach in cricket (comparing strategies used by winning and losing teams) has since been replicated by other researchers (Douglas and Tam, 2010) in the analysis of more recent tournaments (ICC World T20 Cup 2009). The data provides an insight into how batsmen structure a batting innings and indirectly the degree of risk undertaken. Likewise, when and how a captain rotates bowlers during an innings provides important clues as to how various bowling types are utilised. Game strategy and tactics ultimately dictate the workload that particular players undertake, however more direct investigations (utilising time-motion studies) of player movement patterns provide conditioning practitioners with valuable information to utilise in their programme design.

The process of game analysis of elite cricketers has been confined to relatively few studies and observations, speculatively this may be largely due to the time-consuming nature of the earlier (video-based) methods employed. The recent advent and acceptance of GPS in time-motion analysis enables multiple athletes to be tracked simultaneously, and with fast post-processing times the data is quickly disseminated to practitioners. How valid and reliable the GPS measurements are for cricket applications, was an immediate issue that required resolution. Cricket is played over an extended duration, with the majority of movement occurring at walking velocities; previous GPS validation investigations had failed to experiment how GPS units would perform over extended durations (is there measurement drift?), at different times during the day, and over a range of movement velocities specific to cricket. The current investigation looked at various movement velocities and critically validated the units over extended time periods (up to ~90 minutes). Understanding the limitations of GPS technology, and how the reliability and validity differs in relation to movement velocity is critical for practitioners interpreting and ultimately applying the findings of GPS based time-motion studies. Conditioning practitioners require clear, reliable and valid data on positional player types to develop enhanced programmes that allow for improvements in performance. GPS athlete tracking devices are a dynamic quickly improving technology; any validation study is only applicable to the model and type of units investigated and will be relevant for a short time period. Replication of the cricket specific validation study with future GPS units will further improve the application of this technology. The reliability of GPS devices has previously been assessed over non-linear paths using a trundle-wheel to provide the calibrated criterion distance (Edgecomb and Norton, 2006). Future studies should incorporate this design into the validation of GPS devices to assess the non-linear and intermittent speeds specific to cricket. The current validation study assessed the batting-specific movement when running between the wickets;

similarly, researchers may consider assessing the validity of GPS predicted distance with fast bowlers completing a bowling spell.

Time motion studies provide one methodological tool to analyse the game and training demands of cricket. The four game analysis studies (studies 4-7) undertaken provide the beginning of a comprehensive database of positional, performance level, game format and specific movement patterns of elite cricketers. Fast bowlers operated with the greatest intensity across all formats of the game, and compared with other positions, covered 20–80% greater total distance, plus 1.8-to 7-fold greater distance during high-intensity movement patterns (sprinting and striding). Coaches should (where possible) seek fielding placements for their fast bowlers to enhance the recovery between high intensity efforts and limit the potential of fielding tasks impacting on their bowling performance. In general, there are similar patterns of movement in 1-day cricket between state and international games, whereas international cricket generally required 12–34% greater physical demand than academy level cricket. Academy team coaches may look to increase the training and simulated game demands to match these requirements for international cricket.

Future work by researchers should focus on further defining the movement demands of: positional player types (in-fielders vs. out-fielders); actual fielding positions e.g. mid-on or fine leg; players from different geographic regions; age group players and female cricketers. The data collated to date, allows practitioners to identify differences between the playing demands of various positions and design specific training programmes that replicate (or exceed) the anticipated game demands. The unpredictable nature of games usually dictates that a player will not train on a match day, thus conditioning work must be scheduled around playing and travelling requirements. Conditioning coaches may use detailed information on

the game-to-game demands of players to balance conditioning and recovery activities to minimise fitness decrements and maximise physical performance in-season. Therefore, recovery programmes can be tailored to a players' specific position and implemented based on a players involvement in the match.

The physiological analysis of training drills (study 8) provides a scientific basis for the effectiveness of various cricket specific training drills. Conditioning practitioners are able to use this data to modify these specific drills to increase or decrease the intensity of training in line with their desired training goal. Practitioners are also able to compare the training effects with the game demands of a specific game format, thereby allowing the drills to replicate or exceed game demands. Using our training study as a template, practitioners are able to investigate their own drills and database the physiological effects of their own training drills. In the future, as the scientific investigation into the training practices of the game continues, players should be trained according to their position specific requirements, and specialist players may be recruited (or emerging players talent identified) based on their physiologic attributes to fulfil a particular position. With a greater understanding of the position specific requirements, playing standards should be raised to an even higher level.

With the large quantity of games played in conditions of high heat and/or humidity, heat adaptation strategies for cricket need further investigation. Being a summer game, teams often travel from one tour to the next with large differences in climatic conditions. Applied heat research must be practical for the elite cricketer by taking account of the short-time frame between tours, and also specific considerations such as practitioners wanting to limit running volume (generally for fast bowlers). The two heat adaption studies (study 9 and 10) quantifies for practitioners the likely physiological heat adaptations that can be obtained by

implementing practical protocols for the elite cricket environment. Practitioners are able to use these data to modify the design of heat adaption protocols and should continue to experiment to obtain a better more complete heat adaptation of their athletes.

Planned strength and conditioning practices in cricket require a greater scientific basis, and should draw on studies from within cricket. The studies comprising this thesis provide the start of a comprehensive database detailing physiological game and training demands, and also look at ways to enhance the adaption to hot/humid environments. The value of these studies should be evident in their contribution to practitioners' long term annual periodized training plans.

Chapter 9

Conclusions

9.0 Conclusions

The experimental work described in this thesis has provided a detailed quantitative analysis of the physiological demands of elite cricketers in both training and competition.

- In Twenty20 cricket, winning teams captured substantially more wickets in the first and last six overs of the innings, and were more effective in containing the opposition teams' run scoring in the middle eight overs.
- Commercially available GPS units have acceptable validity and reliability for measuring long distances of walking to striding intensity, but there are shortcomings of this technology in reliably measuring shorter cricket-specific sprinting distances. Cricket conditioners should therefore exercise caution when interpreting differences in the patterns of high intensity efforts between games.
- In terms of distance sprinted (per hour), Twenty20 was 22% and 43% more intensive for fast bowlers than One Day and multi-day cricket respectively.
- In contrast, the cumulative sprinting in Twenty20 and One Day games was only 39% and 80% of the daily (6 h) total of 1.4 km sprinted during multi-day cricket.
- Academy fast bowlers covered a total distance of ~22.6, ~13.4, and 5.5 km in multi-day (6 h), One Day, and Twenty/20 innings respectively. Consequently, Twenty20 and One Day cricket required only 24% and 59% of the total distance covered in multi-day cricket.
- A case study of a one day international fast bowler showed that the majority (11 of 15) of the workload characteristics analysed had a low game-to-game variability of 20% or less.
- Game heart rates were similar to training heart rates in low intensity conditioning sessions, but substantially lower than heart rates recorded in high intensity conditioning sessions.

- Comparisons made between time-motion data of training activities and the match data showed that simulation and skill drills did not exceed game demands.
- Four 30-45 min high intensity cycling sessions in hot/humid conditions elicited only partial heat acclimation.
- Substantial adaptations in core temperature, heart rate, sweat rate and perceived exertion in cricketers require more than four sessions of heat acclimation.
- Moderate to large changes in sweat electrolyte concentrations can occur in the first few days of heat acclimatisation in elite cricketers.

9.1 Implications

The practical implications and knowledge that practitioners should be aware of from this thesis are:

- The first two studies identified strategies and tactics used by successful sides during both One Day International and Twenty20 cricket matches. In Twenty20 cricket, captains and coaches should employ wicket taking bowlers in the first and last six overs, and more defensive run-containing bowlers and field placement in the middle eight overs.
- The comprehensive GPS validation study demonstrated that temporal longitudinal comparison of GPS data can be made with confidence. However sampling frequency and movement velocity needs to be considered when measuring cricket-specific distances.
- Conditioning coaches can design training and recovery programmes accounting for a typical variability in workload characteristics of <20%.

- Fast bowlers should be conditioned to sprint more often in preparing for Twenty20 cricket. When preparing for multi-day cricket elite fast bowlers need to be conditioned to manage a total sprint distance of ~1.8 km per day.
- To train players to execute their skills under a higher level of physical demand than actually required in a game it may be appropriate to programme a conditioning drill immediately prior to a cricket simulation drill.
- Physiological adaptations can be accelerated with prior heat acclimation sessions before embarking on an overseas sub-continental tour. However, only partial heat adaptation can be expected after four 30-45 min cycling sessions of acclimatisation.
- A more intensive and extensive acclimation programme is needed for cricket players required to play within a few days of arriving in hot/humid climates.
- Four days of acclimatization provided only slightly superior results to a four day heat acclimation programme.

9.2 Limitations

Although the findings of this thesis have useful implications, the following limitations apply:

- The validation and reliability data for the GPS units investigated relate to the current state of the technology (software, firmware and hardware) at the time of the main data collection (2007-2009). Over the three years of this PhD the specified frequency of GPS chip sets in commercially available GPS devices for sporting applications increased from 1 to 15 Hz. The increased frequency has improved (and rectified) many of the earlier limitations apparent in regard to estimating the distance covered in the short distance higher speed movement categories.
- The findings are limited to highly-trained male cricket players.

- Most physiological data (e.g., heart rate and blood lactate) was obtained using academy cricketers (during matches for study six), and not international cricketers. Obtaining this data (in combination with the GPS data collected) using international cricketers would be logistically difficult given the level and importance of the matches investigated.
- The sample sizes of the heat acclimation and acclimatisation groups were relatively small. However the players tested represented the total touring squad travelling to India.

9.3 Directions for Future Research

- Effective periodisation plans for managing elite cricket athletes need developing and evaluating. Unlike most sports, cricketers compete more often than they train and typically are involved in a 10-month competitive year.
- Quantifying longitudinal changes in physical and physiological characteristics of players across a 12 month period of competition would assist coaches in planning and evaluating conditioning and testing programmes.
- Quantifying physiological and movement demands of match play at various levels of competition, especially at the age-group level and in women's cricket would assist conditioning coaches prescribe level- and gender-specific fitness and recovery programmes.
- Physiological and movement pattern data on a wider range of typical training activities and drills would provide the basis to prescribe game-specific conditioning and other training or intervention (acclimation) strategies.
- Reliable laboratory and particularly field-based methods to measure player fatigue are needed to develop better guidelines for advising coaches and players on short-term (game) and long-term (tour or season) fatigue.
- Magnitudes of differences in the movement and physiological demands of outfielders and infielders and specific fielding roles need to be established.

- Practical guidelines to individualise conditioning and recovery programmes based on the actual movement demands performed in matches need development and evaluation.

Appendix – A

Conference presentation

Petersen, C. Cricket Australia GPS research programme 2007-2010, Cricket Australia, Sports Science Sport Medicine Conference, Brisbane, Queensland, Australia 16-18 May 2007

Cricket Australia GPS Research Program 2007 – 2010

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Cricket Australia, the Australian Institute of Sport, and the University of Western Australia have established a joint Cricket PhD Scholarship in physiology and performance analysis. The scholarship will run from 2007 to 2010.

The primary aim of the scholarship is to conduct applied research that provides short to medium term benefits for Cricket Australia in the areas of fitness, physical preparation and game analysis. A secondary aim of the scholarship is to provide sports science - physiology support to various Cricket Australia programs including the national teams and the AIS Cricket program at the Centre of Excellence.

The possible areas of research currently under consideration are:

- ☐ Defining the physical demands imposed upon players in Twenty/20, 50 over and first class cricket.
- ☐ Quantifying the changes and differences in fitness levels within and between players using contemporary fitness testing and new sensor technologies (GPS and accelerometry).
- ☐ Effectiveness of training interventions in enhancing cricket-specific fitness.
- ☐ Practical methods and strategies to monitor the longitudinal training (competition) load on players and to enhance recovery from various training and playing stresses.
- ☐ Enhancing the preparation of cricketers for challenging environmental conditions (heat and humidity).
- ☐ Individualising training prescription based on positional requirements.
- ☐ Optimising player fielding rotation utilising real-time movement and physiological responses.

I have played cricket for over twenty years, the highlight has been beating the MCC in a game with my District Association Horowhenua-Kapiti. I have a Bachelors Degree, a Post Graduate Diploma (Sports Medicine) and a Masters Degree in Exercise Physiology from the University of Otago, New Zealand. My Masters thesis involved a controlled intervention study with cricket fast bowlers published in the Journal of Sport Sciences 22(11-12): 1035 – 1039 (Effects of modified-implement training on fast bowling in cricket). I completed a work experience placement in the Physiology Department of the A.I.S. (Canberra), before working for 2 years at the New Zealand Academy of Sport (Wellington), and 2 1/2 years as a sport scientist in Ireland.

Acknowledgement: I would like to express my gratitude to Cricket Australia, AIS and UWA for making this possible and I look forward to contributing to the success of Australian Cricket.

Appendix – B

Conference presentation

Petersen, C. Pyne, D.B., Dorman, J., and Portus, M.R. GPS monitoring during the COE 2006 Emerging Players Tournament. Cricket Australia Sports Science Sport Medicine Conference, Brisbane, Queensland, Australia, 16-18 May 2007

GPS monitoring during the 2006 CBCE Emerging Players Tournament

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Miniature smart sensor technology is moving measures of fitness and performance away from the laboratory environment and on to the cricket field. We used global positioning system (GPS) technology in a pilot study during the four-nation Emerging Players tournament in Brisbane in July 2006. The technology is still in its infancy but will make a substantial contribution to better understanding of the fitness requirements of cricket. An ability to measure and gain a greater understanding of the physical loading experienced by cricketers should facilitate development of more effective and individualised conditioning methods and better monitoring of individual player workloads.

The study was conducted at the 2006 CBCE Emerging Players Tournament in Brisbane held from 10-16 July 2006. Selected players were monitored during several Twenty/20 and one-day games using the latest smart sensor device the AIS MinimaxX GPS unit. The device samples at 5hz and incorporates 150hz triaxial accelerometry capabilities with remote radio frequency transmission. The device is the size of a small mobile phone measuring only 4 x 8 x 1.5 cm and was inserted into a small harness positioned unobtrusively between the players' shoulder blades. We collected data from bowlers, batsmen, wicketkeepers and fielders.

The AIS MinimaxX software collated the data into 5 different movement categories based on speed [Walking (0-7 $km.h^{-1}$), jogging (7-14 $km.h^{-1}$), striding (14-21 $km.h^{-1}$), fast running (21-28 $km.h^{r-1}$) and sprinting (28 - 35 $km.hr^{-1}$+)]. The software further analysed the data to show; the total distance covered, the number of efforts and the time spent within each category, and the number of accelerations between different movement categories.

Fast bowlers covered the greatest distance in both Twenty/20 and 50 over games with averages of 6.7 and 13.1 km respectively (Tables 1 and 2). In comparison, fielders covered up to 10 km in a 50 over game with the distribution of efforts dependent upon position and involvement in the game. Wicketkeepers covered approximately 10 km in a 50 over game: walking and jogging comprise approximately 90% of the distance with the remainder made up of a small number of runs, strides and sprints. The distance that batsmen covered was dependent upon the length and composition of their innings. There are a few 100% sprints evident across all of the different player categories' and irrespective of position' approximately 80-90% of distance is either spent walking or jogging. Fast bowlers can cover up to 1000 m at the level of striding in a 50 over game however further analysis is required to divide this distance into bowling and out-fielding.

The development of smart sensor technology allows sport scientists to measure the actual physical demands that players encounter in a variety of training and competition settings. Until now video analysis was used for time-motion studies, however this approach is very time consuming and labour intensive making it impractical for everyday usage. GPS technology will allow a greater understanding of the physical demands of the game facilitating the creation of more appropriate conditioning drills to enhance fitness attributes and overall player performance. When fully implemented the real-time technology also opens up practical methods to optimise player recovery by minimising player fatigue e.g. improving the rotational strategies via the usage of substitute fielders. The technology is still in the developmental stage and a number of small technical issues need to be resolved, including software improvements customised for cricket, automatic generation of group and individual reports, and easier

integration with video and other sensors. Hardware improvements we identified included more robust harness systems, improved battery life and synchronisation of GPS, heart rate, and digital video.

Fast bowlers appear to have the greatest movement loads during Twenty/20 and 50 over games. The majority of the distance covered is by walking and jogging, although the distribution and quality of higher intensity efforts is likely to be more closely linked to game and performance outcomes. Further development and testing is required to address the key questions facing coaches and players. Will enhanced fitness or recovery strategies be associated with changes in the movement pattern distribution of cricketers? How do different environmental conditions affect player movements and physical loads? This technology provides a tool to quantify the characteristics of physical loading on players in both training and competition, thus paving the way for better longitudinal monitoring of player recovery and physical adaptation.

Table 1: Distance (m) covered in 50 over games – Data expressed as mean (s.d)

Activity– (no. Athletes)	Walk	Jog	Stride	Fast running	Sprinting	Total
Fast bowling (4)	8758	2306	1131	872	21	13088
	(1168)	(567)	(218)	(135)	(14)	(1041)
Spin bowling (2)	4789	2128	489	32	5	7443
	(3475)	(1377)	(297)	(8)	(7)	(5150)
Wicket keeping (2)†	4611	1841	347	42	9	6849
	(2952)	(836)	(35)	(18)	(6)	(3835)
In-Fielding (2)	4550	1413	376	60	35	6433
	(3284)	(418)	(207)	(71)	(47)	(4027)
Batting* (12)	1416	297	219	23	0	1955
	(967)	(213)	(158)	(25)	(1)	(1292)

* Average Fast bowling spell = 54 deliveries, Average Spin bowling spell = 42 deliveries
** Average batting innings analysed = 40 runs, 58 mins, 43 balls, 3 x 4's, 1 x 6's
† Data incomplete for one trial

Table 2: Distance (m) covered in Twenty/20 games – Data expressed as mean (s.d)

Activity– (no. Athletes)	Walk	Jog	Stride	Fast running	Sprinting	Total
Fast bowling (4)	3867	1622	734	451	19	6692
	(728)	(483)	(145)	(142)	(27)	(1080)
Spin bowling (2)	3464	1310	318	53	6	5150
	(39)	(358)	(179)	(6)	(6)	(575)
Wicket keeping (2)	2384	930	199	21	2	3535
	(750)	(595)	(146)	(13)	(0)	(1502)
In-Fielding (3)	3216	1256	328	55	7	4861
	(1037)	(325)	(143)	(55)	(10)	(575)
Batting* (12)	725	210	200	26	0	1161
	(361)	(114)	(131)	(18)	(1)	(601)

* Average Fast bowling spell = 21 deliveries, Average Spin bowling spell = 24 deliveries
** Average batting innings analysed = 25 runs, 25 mins, 20 balls, 2 x 4's, 1 x 6's

Appendix – C

Conference presentation

Petersen, C. Pyne, D.B., Dawson, B., and Portus, M.R. Quantification of seasonal game-load of International Fast bowlers. Australian Applied Physiology Conference, Canberra 13 Nov 2009

Quantification of seasonal game-load of international fast bowlers

Carl Petersen[1,2,3], David Pyne[1] Brian Dawson[2] and Marc Portus[3]

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Introduction

To identify periods of increased injury susceptibility we used global positioning system (GPS) defined game-load with rolling weekly averages. It has been established that high game workload of cricket fast bowlers results in a delayed increased injury susceptibility; peaking 21 to 28 days after the initial acute high workload, possibly via a mechanism of damaging immature (repair) tissue. The irregular and crowded game scheduling of the international cricket calendar makes it difficult to predict these periods.

Methods

Fast bowlers' movement patterns (113 game files, from 17 fast bowlers) have previously been quantified utilising portable 5Hz global positioning system (GPS) units (Catapult, Melbourne, Australia). Combining this data with the 2008 international game schedule; (Australian cricketers had 100 competitive playing days: 5x tour games, 2 x Twenty20, 18 x ODI, 14 x Test matches) games were assigned values of the mean distance covered in each game format (Twenty20 = 8.5; ODI = 15.0; Test 12.0 km/day). Rolling averages (7 and 28-day) expressed as weekly volume (km), were utilised to identify periods of sudden and/or sustained high game-load.

Results

Fast bowlers' peak weekly game-load was 60 km. This occurred 14 times during the year, in three blocks and in sequence with the timing of Test matches. The most sustained period of high weekly game-load was weeks 41 - 49 (7th October – 2nd December) with 42 ± 19 km (mean ± sd) covered per week. During the year, there were 18 and 9 weeks with no 7-day and 28-day game-load respectively. The break from 28-day game-load occurred in two blocks, 6 and 3 weeks respectively. The greatest discrepancy between the 7-day and 28-day rolling average was at week 21 (3rd Week May), with a 51 km difference in weekly game-load, coinciding with the start of a test match tour.

Discussion/Conclusion

GPS game analysis enables quantification of predicted game-load and provides conditioning coaches with a method to plan and periodise subsequent fast bowler workload. Long-term planning with short-term training modification is crucial to ensure fast bowlers maintain fitness levels with reduced injury risk.

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Appendix – D

Conference presentation

Pyne, D.B. **Petersen, C.** Higham, D.G. Cramer, M.N. (2010).

Comparison of 5- and 10-Hz GPS technology for team sport analysis.

Presented by Prof. David Pyne at the American College of Sports

Medicine conference in Baltimore, USA. June 3 2010

2010. Medicine and Science in Sports and Exercise 42(5) 78

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May 2010 - Volume 42 - Issue 5 - p 78
doi: 10.1249/01.MSS.0000385563.66526.6d
D-58 Free Communication/Slide - Reliability of Fitness Testing Measures: JUNE 3, 2010 3:15 PM - 5:15 PM: ROOM: 337

Comparison Of 5- And 10-Hz GPS Technology For Team Sport Analysis: 837: June 3 3:15 PM - 3:30 PM

Pyne, David B. FACSM; Petersen, Carl; Higham, Dean G.; Cramer, Matthew N.

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(No disclosure reported)

Game and training analysis in team sports is increasingly reliant on application of smart sensor devices and wireless technology.

PURPOSE: To compare the reliability and validity of 5- and 10-Hz global positioning system (GPS) devices for quantifying distances of short sprints in team sport athletes.

METHODS: Twenty trials of maximal effort short sprints over 10-, 20-, 30- and 40-m intervals using a MinimaxX GPS device (Team Sport Version 4.0 10-Hz, Catapult, Melbourne, Australia) were evaluated against a criterion measure of electronic timing (Swift timing gates, Lismore, Australia; accurate to 0.01 s). Data were log-transformed before analysis to reduce the non-uniformity of error. Validity was quantified with the standard error of the estimate (SEE) and reliability estimated using the typical error expressed as a coefficient of variation. These estimates were then compared with previously established values for a 5-Hz device (Team Sport Version 2.5) for 20-, 30- and 40-m intervals.

RESULTS: The estimates of validity (standard error of the estimate ± 90% confidence limits) of the new 10-Hz device were: 10-m, 13.9 ± 5.1%; 20-m, 8.8 ± 3.2%; 30-m, 6.2 ± 2.3%; and 40-m, 5.0 ± 1.8%. The estimates of reliability (typical error ± 90% confidence limits) for the 10-Hz device were: 10-m, 11.7 ± 3.6%; 20-m, 6.9 ± 2.1%; 30-m, 4.7 ± 1.4%; and 40-m, 3.8 ± 1.1%. Comparable mean estimates for the older 5-Hz device over 20-40 m intervals ranged from 14-24% for validity, and 16-30% for reliability.

CONCLUSIONS: The reliability and validity of estimates for quantifying the distance covered in short sprints is markedly better using 10-Hz GPS technology.

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Appendix – E

Conference poster presentation

Petersen, C. Pyne, D.B., Portus, M.R., Dawson, B and Kellett, A. Comparison of Twenty20 game demands in the early season versus the peak competitive season. Poster session presented at the 'Be Active' Sports Medicine Australia Conference, Brisbane, QLD, Australia. 14-17 Oct 2009

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Program and Abstracts

Supplement to

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2009 Australian Conference of Science and Medicine in Sport

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SPORTS MEDICINE AUSTRALIA

235 An explosive approach to stabilise the hip and pelvis during running

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Introduction: Instability at the hip and pelvis joints has been linked to common overuse injuries. Conventionally, athletes, who are at risk of injury, but competing pain free and unrestricted, are prescribed slow controlled exercises to improve stability through strengthening the gluteus medius (GM). We contend that based on principles of 'specificity', explosive strength training will be more effective for these athletes compared to conventional approaches. The aim of this study was to compare the effectiveness of training pelvis and hip stability using either slow controlled or explosive training.
Method: State Institute netballers (n=8, age=20.1±2.1years, stature=178.2±4.1cm, mass=69.1±4.7kg) performed a standardised running protocol on a motorised treadmill (Starting at 8 km/h increasing 2 km/h every four minutes and finishing at 14km/h) on three occasions. Parameters included: frontal plane kinematics (e.g., peak pelvic obliquity and hip adduction angle) using VICON Mx, Motion Analysis System (500Hz); electromyography recordings (1000Hz) of GM and tensor fascia latae (both sides); and oxygen kinetics. Test 1 and 2 were for reliability purposes and attainment of baseline data. Participants were divided into either explosive or slow controlled groups, matched for hip and pelvis kinematics. Following eight weeks of training a final test session was performed. One netballer dropped out during the intervention phase of the study due to illness and did not complete the final testing session.
Results/Discussion: Selected parameters displayed acceptable reliability based on the typical error of measurement and the smallest worthwhile change. Analyses were performed on 12 and 14km/h data sets only. The key findings were that eight weeks of training improved stability of the hip and pelvis regardless of group membership by reduction in peak angles in all but one of the kinematic parameters measured. Differences between groups were found. The explosively trained group displayed changed GM onset times, where GM activation occurred earlier prior to ground contact when running. No change or in some cases a decrement were found in the slow controlled group. These preliminary findings, whilst limited by sample size, support the use of explosive training rather than conventional approach to improve hip and pelvis stability in terms of frontal plane kinematics. Differences in GM onsets support the notion of specific training adaptations, and the mechanism for hip and pelvis stability may not be the same for both groups. Finally, following training, only the explosive group improved running performance (economy) further justifying this method of prescription.

236 Comparison of Twenty20 game demands in the early season versus the peak competitive season

C. Petersen[1,2,3*] ▪ D. Pyne[2] ▪ M. Portus[1] ▪ B. Dawson[3] ▪ A. Kellett[1] ▪ [1]Cricket Australia ▪ [2]Australian Institute of Sport ▪ [3]University of Western Australia

Purpose: To quantify differences in the workload of elite cricketers between early (July) and peak competitive season (January) Twenty20 (T20) cricket tournaments.
Methods: Player movement patterns for batsmen, fast and spin bowlers, fielders, and wicketkeepers were quantified utilising portable 5Hz global positioning system (GPS) units (Catapult, Melbourne, Australia) during six early (30 National academy players; 96 files; 23.2 ± 2.6 y; mean ± SD) and four peak (18 State players; 30 files; 26.7 ± 2.6 y) season games. Logan Plus 4.0 software (Catapult Innovations, Melbourne, Australia) was used to estimate the cumulative distance covered in five movement categories (standing / walking, jogging, running, striding and sprinting).
Results: Across all positions, fast bowlers in the peak season competition had the highest sprinting workload. During an 80min innings fast bowlers covered a total distance of 8.5 ± 1.5km in the peak season, with 0.7 ± 0.2km sprinting (above 18 km.h-1), and sprinted 42 ± 8 times with a mean distance of ~17m. Fast bowlers in the peak season covered 53% more total distance (difference +3.0km) and 33% more in sprinting (+180m) than the early season. Batsmen in the peak season (30min innings) covered 2.4 ± 0.5km in total distance including ~160 ± 80m sprinting with 12 ± 5 sprints. During an innings in the peak season, wicketkeepers rarely sprinted with only 5 ± 2 sprints which contributed to a total sprint distance of 60 ± 40m. Walking and jogging intensities (<3.5 km.h-1) accounted for the majority (92%) of the 6.4 ± 0.7km total distance covered by wicketkeepers in the peak season. Similarly, spin bowlers in both the early and peak season covered ~92% of their total distance in walking and jogging intensities; while sprinting accounted for just 2% of spin bowlers' total distance. In comparison, 7 – 9% of total distance was covered sprinting by fielders, fast bowlers and batsmen in the peak season. Batsmen, wicketkeepers and spin bowlers covered twice the total distance (2.4, 6.4 and 8.5km respectively) in the peak season compared with the early season games.
Conclusions: The ~50 – 100% higher total distance covered in peak season games highlights the potentially important lower game intensity demands that an out of season tournament possesses. This has implications for the preparation of cricketers for tournaments occurring overseas and out of the traditional cricket season; a feature of the modern cricket landscape!

237 A review of strength and conditioning programs designed to improve fitness in golfers

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Background: The golf swing is a complex and athletic movement that requires strength, flexibility and coordination. Strength and conditioning programs have the potential to improve performance through fitness adaptations. The aim of this review was to evaluate the effectiveness of strength and conditioning programs on measures of golf specific fitness (strength, power, balance, flexibility).
Methods: Studies were sourced via electronic library databases, hand searched sport science journals and scanning through relevant studies' reference lists.
Results: 12 studies were identified. Most studies used middle aged to older (29 – 79yrs) male recreational golfers and 2 studies used collegiate golf students (18 – 25yrs) of both sexes. The majority of the programs ran for approximately 8 weeks and participants were required to complete 2 – 4 sessions per week for an average duration of 60 90 minutes. Resistance training (RT) programs involved machine weights, free weights, medicine balls and elastic bands and all studies included a flexibility component. Most studies assessed changes in fitness characteristics and generally resulted in improvements. All of the studies assessed changes in club head speed and reported increases (range 2 – 13%). X factor (difference between hip and upper torso rotations at the top of the backswing) was assessed in one study and improved (7%) as a result of training.
Conclusion: The findings from this review suggest that strength and conditioning programs can have a positive effect on the golf swing and fitness characteristics. The majority of studies included in this review evaluated the effects of generic RT programs on fitness characteristics and club head speed. Future studies should investigate the effects of more specific strength and conditioning programs to improve golf specific fitness.

Appendix – F

Raw Data

Study 1: World Cup game statistics – Round Robin Stage

Date (March)	Team	Favourite	Toss won by	Decided to	Game result	Runs scored	Overs batted	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Maidens bowled	Wickets taken	Spin overs bowled	50+ run partnerships	No balls & wides bowled
13	WI				Won	241	50.0	4.82	7	24	138	73	5	10	0	2	2
	PAK	PAK	PAK	Bowl	Lost	187	47.2	3.96	2	15	72	97	7	9	22	1	9
14	AUS	AUS			Won	334	50.0	6.68	9	32	182	87	4	10	13.1	4	7
	SCO		SCO	Bowl	Lost	131	40.1	3.27	0	12	48	55	0	6	17	0	6
14	KEN	KEN	KEN	Bowl	Won	203	43.2	4.70	2	17	80	54	5	10	10	2	9
	CAN				Lost	199	50.0	3.98	2	21	96	65	1	3	21	0	20
15	SRI	SRI	SRI	Bat	Won	321	50.0	6.42	3	24	114	107	6	10	6.4	2	3
	BER				Lost	78	24.4	3.20	2	8	44	14	1	6	16	0	27
15	ZIM	ZIM	ZIM	Bowl	Tie	221	50.0	4.42	1	26	110	57	7	9	17	2	8
	IRE				Tie	221	50.0	4.42	2	22	100	69	8	10	12	1	9
16	SAF	SAF			Won	353	40.0	8.83	18	30	228	88	5	9	8	3	3
	HOL		HOL	Bowl	Lost	132	40.0	3.30	1	17	74	44	2	3	4	0	9
16	ENG				Lost	209	50.0	4.18	2	15	72	92	1	4	15	2	13
	NZ	NZ	NZ	Bowl	Won	210	41.0	5.12	1	17	74	73	1	7	15	2	11
17	IND	IND	IND	Bat	Lost	191	49.3	3.87	1	13	58	74	4	5	21	1	12
	BAN				Won	192	48.3	3.98	5	17	98	59	8	10	30	1	11
17	PAK	PAK			Lost	132	45.4	2.91	0	13	52	33	1	7	5	0	12
	IRE		IRE	Bowl	Won	133	41.4	3.21	2	10	52	46	8	10	5.4	0	26
18	AUS	AUS	AUS	Bat	Won	358	50.0	7.16	13	34	214	98	1	10	4.5	2	5
	HOL				Lost	129	26.5	4.87	2	17	80	29	3	5	7.5	0	10
18	ENG	ENG			Won	279	50.0	5.58	3	25	118	94	2	7	13	3	14
	CAN		CAN	Bowl	Lost	228	50.0	4.56	4	20	104	72	1	6	25.1	2	13
19	IND	IND			Won	413	50.0	8.26	18	31	232	110	3	10	14.1	2	15
	BER		BER	Bowl	Lost	156	43.1	3.62	2	15	72	41	1	5	15	0	24
19	WI	WI	WI	Bowl	Won	204	47.5	4.29	6	16	100	65	3	5	20	2	15
	ZIM				Lost	202	50.0	4.04	1	17	74	83	4	4	13	2	12
20	SAF	SAF	SAF	Bowl	Won	188	23.2	8.10	4	26	128	44	4	8	0	1	6
	SCO				Lost	186	50.0	3.72	3	17	86	70	0	3	11.2	1	1
20	NZ	NZ			Won	331	50.0	6.62	12	24	168	82	4	10	10	3	10
	KEN		KEN	Bowl	Lost	183	49.2	3.72	4	13	76	60	0	7	7	0	25

Study 1: World Cup game statistics – Round Robin Stage (Continued)

Date (March)	Team	Favourite	Toss won by	Decided to	Game result	Runs scored	Overs batted	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Maidens bowled	Wickets taken	Spin overs bowled	50+ run partnerships	No balls & wides bowled
21	SRI	SRI			Won	318	50.0	6.36	12	20	152	97	6	10	13	3	5
	BAN		BAN	Bowl	Lost	112	37.0	3.03	1	12	54	42	0	4	20	0	13
21	ZIM		ZIM	Bowl	Lost	99	19.1	5.18	6	4	52	24	3	10	12	0	14
	PAK	PAK			Won	349	49.5	7.05	16	27	204	100	1	10	10	3	3
22	SCO				Lost	136	34.1	3.99	2	17	80	30	2	2	6.5	0	2
	HOL	HOL	HOL	Bowl	Won	140	23.5	5.96	1	25	106	20	6	10	8	1	10
22	NZ	NZ			Won	363	50.0	7.26	11	29	182	107	1	9	19.2	3	14
	CAN		CAN	Bowl	Lost	249	49.2	5.06	2	25	112	85	2	5	30	2	18
23	IND	IND	IND	Bowl	Lost	185	43.3	4.27	2	16	76	74	2	6	10	1	16
	SRI				Won	254	50.0	5.08	1	22	94	101	2	10	19	1	7
23	WI	WI			Won	190	38.1	4.99	7	17	110	57	3	8	15	1	8
	IRE		IRE	Bat	Lost	183	48.0	3.81	2	14	68	68	2	2	11	1	6
24	AUS				Won	377	50	7.54	11	40	226	115	1	10	12	3	12
	SAF	SAF	SAF	Bowl	Lost	294	48	6.13	6	32	164	97	0	6	0	2	10
24	ENG	ENG			Won	178	33	5.39	2	19	88	49	0	10	8	1	14
	KEN		KEN	Bat	Lost	177	43	4.12	0	15	60	68	0	3	9	0	10
25	BER				Lost	94	21	4.48	2	6	36	31	1	3	5.3	0	17
	BAN	BAN	BAN	Bowl	Won	96	17.3	5.55	1	5	26	35	0	9	7	1	6
Mean						215	42.4	5.02	4.5	19.4	104.9	67.4	2.8	7.2	12.4	1.3	11.1
SD						85	9.4	1.49	4.8	7.8	53.9	26.6	2.4	2.7	7.0	1.1	6.2

Study 1: World Cup game statistics – Super Eights Stage

Date (March/ April)	Team	Favourite	Toss won by	Decided to	Game result	Runs scored	Overs batted	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Maidens bowled	Wickets taken	Spin overs bowled	50+ run partnerships	No balls & wides bowled
27	WI		WI	Bowl	Lost	219	45.3	4.83	2	18	84	76	2	6	13	1	11
	AUS	AUS			Won	322	50.0	6.44	6	27	144	94	2	10	14	3	15
28	SAF	SAF			Won	212	48.2	4.40	1	14	62	102	1	10	5	2	5
	SRI		SRI	Bat	Lost	209	49.3	4.24	0	18	72	82	1	9	20	1	4
29	WI				Lost	177	44.4	3.99	1	16	70	66	2	3	7.2	1	5
	NZ	NZ	NZ	Bowl	Won	179	39.2	4.57	1	18	78	60	6	10	9	1	3
30	IRE				Lost	218	48.1	4.53	2	12	60	83	2	7	12	2	14
	ENG	ENG	ENG	Bat	Won	266	50.0	5.32	4	22	112	98	5	10	19	3	14
31	AUS	AUS	AUS	Bowl	Won	106	13.5	7.85	4	11	68	27	0	6	7.2	1	7
	BAN				Lost	104	22.0	4.73	2	4	28	53	0	0	6	0	0
1	WI		WI	Bowl	Lost	190	44.3	4.29	6	8	68	83	2	5	12	1	18
	SRI	SRI			Won	303	50.0	6.06	7	16	106	93	4	10	20.3	1	6
2	BAN				Lost	174	48.3	3.60	2	12	60	78	0	1	13.2	1	11
	NZ	NZ	NZ	Bowl	Won	178	29.2	6.10	4	14	80	54	7	10	10	1	2
3	IRE				Lost	152	35.0	4.34	2	14	68	56	1	3	7	0	5
	SAF	SAF	SAF	Bowl	Won	165	31.3	5.27	1	18	78	55	4	8	0	2	4
4	ENG		ENG	Bowl	Lost	233	50.0	4.66	2	18	84	97	1	10	11	2	8
	SRI	SRI			Won	235	50.0	4.70	1	15	66	85	5	8	18	1	4
7	BAN				Won	251	50.0	5.02	3	26	122	80	3	10	19.4	2	12
	SAF	SAF	SAF	Bowl	Lost	184	48.4	3.80	3	10	58	86	3	8	0	0	17
8	AUS	AUS			Won	248	47.2	5.25	1	28	118	79	1	10	14	2	9
	ENG		ENG	Bat	Lost	247	49.5	4.99	2	18	84	95	3	3	9	2	5
9	IRE				Lost	134	37.4	3.58	3	7	46	51	1	8	20	1	12
	NZ	NZ	NZ	Bat	Won	263	50.0	5.26	3	19	94	95	5	10	15.4	2	10
10	WI		WI	Bowl	Lost	289	50.0	5.78	5	22	118	113	0	4	10	2	6
	SAF	SAF			Won	356	50.0	7.12	14	24	180	111	1	9	0	3	3
11	ENG	ENG	ENG	Bowl	Won	147	44.5	3.30	3	10	58	47	2	10	7	0	12
	BAN				Lost	143	37.2	3.84	1	14	62	41	10	6	20	0	5
12	SRI	SRI			Won	218	45.0	4.84	1	14	62	94	5	7	20	1	9
	NZ		NZ	Bat	Lost	219	50.0	4.38	2	12	60	94	2	4	10	3	11
13	AUS	AUS	AUS	Bowl	Won	92	12.2	7.54	2	8	44	13	6	10	6	1	13
	IRE				Lost	91	30.0	3.03	0	7	28	18	0	1	1	0	9

Study 1: World Cup game statistics – Super Eights Stage (Continued)

Date (March/ April)	Team	Favourite	Toss won by	Decided to	Game result	Runs scored	Overs batted	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Maidens bowled	Wickets taken	Spin overs bowled	50+ run partnerships	No balls & wides bowled
14	SAF				Lost	193	50.0	3.86	3	8	50	90	0	5	7	1	9
	NZ	NZ	NZ	Bowl	Won	196	48.2	4.07	1	18	78	71	6	7	20	2	6
15	BAN				Lost	169	41.2	4.10	2	15	72	45	2	7	19	0	11
	IRE	IRE	IRE	Bat	Won	243	50.0	4.86	3	10	58	79	2	10	8	1	18
16	AUS	AUS			Won	232	42.4	5.47	5	22	118	66	4	10	21	3	14
	SRI		SRI	Bat	Lost	226	49.4	4.57	3	17	86	80	1	3	19.4	1	9
17	SAF	SAF			Won	157	19.2	8.18	0	23	92	30	8	10	0	2	8
	ENG		ENG	Bat	Lost	154	48.0	3.21	1	13	58	59	0	1	2	1	5
18	IRE				Lost	77	27.4	2.81	1	8	38	23	0	2	5	1	8
	SRI	SRI	SRI	Bowl	Won	81	10.0	8.10	2	10	52	8	7	10	1	0	4
19	WI	WI			Won	230	50.0	4.60	4	13	76	106	4	10	8.5	2	9
	BAN		BAN	Bowl	Lost	131	43.5	3.01	0	9	36	55	4	5	20	1	7
20	AUS	AUS	AUS	Bat	Won	348	50.0	6.96	6	31	160	126	1	10	6.5	3	9
	NZ				Lost	133	25.5	5.22	1	12	54	36	0	6	20	0	15
21	WI				Lost	300	49.5	6.06	4	33	156	98	2	9	10	2	5
	ENG	ENG	ENG	Bowl	Won	301	49.5	6.08	3	27	126	105	1	10	13	3	17
Mean						202	41.4	4.98	2.7	15.9	79.8	71.6	2.7	7.1	11.2	1.4	8.8
SD						69	11.2	1.33	2.4	6.8	34.4	28.5	2.4	3.2	6.7	1.0	4.5

Study 2: IPL game statistics

Game	Team	Toss Won by	Decided to	Game result	Runs scored	Balls faced	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Dot balls faced	Wickets taken	Maidens bowled	Spin overs bowled	25+ run partnerships	Value 25+ run partnerships	No balls & wides bowled
1	Bangalore	Bangalore	Bowl	Lost	82	91	5.47	3	3	30	27	65	3	0	4	0	0	4
	Kolkata			Won	222	120	11.10	14	15	144	39	27	10	0	0	4	222	10
2	Punjab			Lost	207	120	10.35	9	18	126	58	33	5	0	3	4	180	4
	Chennai	Chennai	Bat	Won	240	120	12.00	16	20	176	40	39	4	0	4	3	235	4
3	Delhi			Won	132	91	8.80	1	18	78	38	37	8	1	4	1	112	2
	Rajasthan	Rajasthan	Bat	Lost	129	120	6.45	3	13	70	42	60	1	0	5	0	0	6
4	Kolkata			Won	112	120	5.60	4	5	44	36	75	10	1	11	1	47	6
	Deccan	Deccan	Bat	Lost	110	120	5.50	6	6	60	31	72	5	0	4	2	58	8
5	Mumbai	Mumbai	Bat	Lost	165	120	8.25	5	18	102	42	53	5	0	8	4	132	5
	Bangalore			Won	166	118	8.30	6	15	96	57	41	6	0	2	4	153	3
6	Rajasthan			Won	168	111	9.33	7	17	110	30	55	8	0	7	3	149	3
	Punjab	Punjab	Bat	Lost	166	120	8.30	7	18	114	33	57	4	0	2	2	97	10
7	Deccan	Deccan	Bat	Lost	142	120	7.10	6	12	84	35	60	1	0	3	1	41	5
	Delhi			Won	143	78	11.00	6	15	96	25	32	8	1	0	2	143	2
8	Chennai			Won	208	120	10.40	6	24	132	44	46	7	1	4	3	189	8
	Mumbai	Mumbai	Bowl	Lost	202	120	10.10	8	19	124	49	46	5	0	3	3	132	7
9	Deccan			Lost	214	120	10.70	9	24	150	43	43	7	0	6	3	172	3
	Rajasthan	Rajasthan	Bowl	Won	217	119	10.85	14	18	156	48	39	5	0	7	2	158	6
10	Punjab			Won	182	120	9.10	5	18	102	41	46	9	1	4	3	130	6
	Mumbai	Mumbai	Bowl	Lost	116	120	5.80	4	12	72	35	74	10	0	4	2	73	4
11	Chennai			Won	152	102	8.94	5	12	78	38	43	9	0	4	2	152	6
	Kolkata	Kolkata	Bat	Lost	147	120	7.35	4	14	80	43	57	1	0	6	3	89	5
12	Bangalore			Lost	135	120	6.75	7	12	90	33	68	3	0	7	2	84	2
	Rajasthan	Rajasthan	Bowl	Won	138	103	8.12	2	22	100	33	47	8	1	5	2	129	4
13	Punjab			Won	162	117	8.10	3	19	94	39	53	8	0	6	2	108	5
	Delhi	Delhi	Bat	Lost	158	120	7.90	2	18	84	49	50	6	0	3	3	104	6
14	Mumbai			Lost	154	120	7.70	5	14	86	37	59	0	0	4	3	103	4
	Deccan	Deccan	Bowl	Won	155	72	12.92	11	13	118	24	27	7	1	6	1	155	5
15	Bangalore			Lost	165	118	8.25	5	14	86	53	42	5	0	0	2	114	3
	Chennai	Chennai	Bat	Won	178	120	8.90	8	17	116	45	47	10	0	0	2	136	6
16	Kolkata	Kolkata	Bat	Lost	137	120	6.85	3	15	78	46	61	3	0	4	3	109	6
	Mumbai			Won	138	112	7.67	2	17	80	35	60	8	1	4	1	113	5

Game	Team	Toss Won by	Decided to	Game result	Runs scored	Balls faced	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Dot balls faced	Wickets taken	Maidens bowled	Spin overs bowled	25+ run partnerships	Value 25+ run partnerships	No balls & wides bowled
17	Delhi			Won	191	120	9.55	5	21	114	51	34	5	0	7	2	151	1
	Bangalore	Bangalore	Bowl	Lost	181	120	9.05	7	16	106	55	39	5	0	1	3	154	2
18	Rajasthan	Rajasthan	Bat	Won	196	120	9.80	5	22	118	48	44	10	0	4	3	152	7
	Kolkata			Lost	151	115	7.95	6	8	68	50	48	7	0	2	2	97	7
19	Deccan			Lost	164	120	8.20	3	19	94	48	44	3	0	4	3	89	4
	Punjab	Punjab	Bowl	Won	167	113	8.79	2	21	96	47	38	8	0	4	3	163	2
20	Chennai	Chennai	Bat	Lost	169	120	8.45	5	17	98	47	49	2	0	4	2	99	4
	Delhi			Won	172	114	9.05	5	16	94	42	40	6	0	3	2	148	5
21	Bangalore			Won	156	120	7.80	4	15	84	61	39	6	0	4	1	72	2
	Deccan	Deccan	Bowl	Lost	153	120	7.65	5	15	90	55	46	8	0	8	1	96	2
22	Punjab	Punjab	Bat	Won	178	120	8.90	4	22	112	42	52	6	0	1	3	110	2
	Kolkata			Lost	169	120	8.45	9	9	90	38	49	6	0	6	1	104	5
23	Mumbai			Won	162	120	8.10	8	14	104	44	56	10	0	3	2	98	1
	Delhi	Delhi	Bowl	Lost	133	113	7.00	5	9	66	45	46	8	0	2	3	105	4
24	Rajasthan			Won	110	86	7.86	2	10	52	27	49	10	0	5	1	78	2
	Chennai	Chennai	Bat	Lost	109	114	5.74	1	12	54	29	65	2	1	8	2	71	7
25	Bangalore			Lost	126	116	6.63	1	16	70	34	64	4	1	4	2	79	7
	Punjab	Punjab	Bowl	Won	127	110	7.06	3	12	66	37	62	10	0	4	2	79	5
26	Chennai			Lost	144	120	7.20	5	11	74	38	60	3	0	4	2	77	4
	Deccan	Deccan	Bowl	Won	148	108	8.22	7	15	102	34	53	7	0	7	2	101	4
27	Mumbai	Mumbai	Bowl	Won	104	91	6.93	3	7	46	28	55	10	0	2	2	73	5
	Rajasthan			Lost	103	98	6.44	2	9	48	36	47	3	0	2	1	53	8
28	Delhi			Lost	187	120	9.35	3	22	106	58	38	6	0	4	2	166	5
	Chennai	Chennai	Bowl	Won	188	120	9.40	5	20	110	48	43	5	0	4	4	165	6
29	Kolkata	Kolkata	Bat	Won	129	96	8.06	5	12	78	29	45	4	0	2	2	60	3
	Bangalore			Lost	124	96	7.75	2	15	72	36	41	7	0	3	2	73	2
30	Rajasthan	Rajasthan	Bowl	Won	141	96	8.81	2	16	76	35	41	8	0	6	1	109	2
	Deccan			Lost	140	120	7.00	3	15	78	46	53	2	0	7	1	88	5
31	Chennai			Won	181	120	9.05	7	14	98	45	54	9	0	4	3	161	2
	Punjab	Punjab	Bowl	Lost	163	120	8.15	10	8	92	43	49	4	0	4	2	114	11
32	Deccan			Lost	181	120	9.05	8	16	112	37	59	4	0	6	4	127	4
	Kolkata	Kolkata	Bat	Won	204	120	10.20	8	22	136	37	46	7	0	3	2	171	8

Game	Team	Toss Won by	Decided to	Game result	Runs scored	Balls faced	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Dot balls faced	Wickets taken	Maidens bowled	Spin overs bowled	25+ run partnerships	Value 25+ run partnerships	No balls & wides bowled
33	Rajasthan	Rajasthan	Bowl	Won	159	115	8.37	6	13	88	34	59	7	0	4	2	99	3
	Delhi			Lost	156	120	7.80	5	10	70	42	50	7	0	5	2	101	8
34	Punjab			Won	144	91	9.60	7	12	90	37	37	8	1	6	2	144	4
	Bangalore	Bangalore	Bat	Lost	143	120	7.15	2	13	64	54	50	1	0	4	3	85	3
35	Kolkata	Kolkata	Bat	Won	133	120	6.65	3	10	58	58	54	10	0	3	2	75	3
	Delhi			Lost	110	107	6.11	0	13	52	44	50	6	0	4	1	34	8
36	Mumbai	Mumbai	Bowl	Won	158	83	11.29	12	12	120	15	52	6	1	0	2	158	7
	Chennai			Lost	156	120	7.80	3	21	102	32	66	1	0	2	1	95	11
37	Delhi			Won	194	120	9.70	6	18	108	48	39	9	0	4	2	159	2
	Deccan	Deccan	Bowl	Lost	182	120	9.10	9	15	114	50	42	4	0	8	3	129	5
38	Mumbai	Mumbai	Bowl	Won	68	33	11.33	3	8	50	6	20	10	1	0	1	42	6
	Kolkata			Lost	67	92	4.47	1	7	34	21	67	2	0	0	0	0	5
39	Rajasthan			Won	197	120	9.85	3	21	102	47	45	9	0	8	2	197	5
	Bangalore	Bangalore	Bowl	Lost	132	120	6.60	6	10	76	39	64	1	0	6	3	94	6
42	Deccan	Deccan	Bowl	Lost	153	120	7.65	6	13	88	45	54	7	0	11	2	110	8
	Mumbai			Won	178	120	8.90	6	17	104	44	58	7	0	2	3	126	4
43	Bangalore			Lost	154	120	7.70	6	14	92	41	58	5	0	4	4	120	1
	Delhi	Delhi	Bowl	Won	158	110	8.78	3	19	94	42	42	7	0	1	1	90	5
44	Kolkata			Lost	147	120	7.35	6	13	88	42	55	4	1	0	2	64	3
	Rajasthan	Rajasthan	Bowl	Won	150	99	9.38	5	17	98	27	44	8	1	5	3	92	2
45	Mumbai	Mumbai	Bowl	Lost	188	120	9.40	6	17	104	33	55	4	0	8	4	159	4
	Punjab			Won	189	120	9.45	8	18	120	41	49	10	0	6	2	172	5
46	Chennai			Lost	112	120	5.60	2	10	52	32	75	8	1	4	1	60	1
	Bangalore	Bangalore	Bat	Won	126	120	6.30	1	14	62	42	55	8	0	4	2	62	6
48	Punjab	Punjab	Bowl	Won	178	117	8.90	8	13	100	53	40	4	0	9	3	146	1
	Deccan			Lost	175	120	8.75	9	14	110	38	49	4	0	10	3	149	5
49	Chennai			Lost	201	120	10.05	9	19	130	50	42	5	0	6	3	168	2
	Rajasthan	Rajasthan	Bat	Won	211	120	10.55	9	20	134	48	34	7	0	5	2	155	6
50	Delhi	Delhi	Bowl	Won	179	119	8.95	6	20	116	45	41	8	0	4	4	159	7
	Mumbai			Lost	176	120	8.80	7	18	114	47	52	5	0	4	3	136	1
51	Deccan	Deccan	Bat	Lost	165	120	8.25	7	15	102	42	58	5	0	4	2	129	0
	Bangalore			Won	171	114	9.00	7	19	118	44	41	10	0	4	4	129	6
52	Kolkata			Won	175	118	8.75	9	17	122	36	56	6	0	8	3	126	6
	Punjab	Punjab	Bat	Lost	174	120	8.70	5	17	98	47	49	7	0	6	3	140	4

Game	Team	Toss Won by	Decided to	Game result	Runs scored	Balls faced	Run rate	6's scored	4's scored	Runs from boundaries	1's scored	Dot balls faced	Wickets taken	Maidens bowled	Spin overs bowled	25+ run partnerships	Value 25+ run partnerships	No balls & wides bowled
53	Rajasthan	Rajasthan	Bowl	Won	146	120	7.30	2	11	56	52	51	7	0	7	2	99	7
	Mumbai			Lost	145	120	7.25	1	14	62	41	57	5	0	2	2	97	6
54	Deccan	Deccan	Bat	Lost	147	120	7.35	3	13	70	49	55	3	0	7	2	118	8
	Chennai			Won	148	116	7.79	3	16	82	42	57	8	0	4	4	148	6
55	Bangalore			Lost	122	108	6.78	2	11	56	40	55	1	0	4	3	109	6
	Mumbai	Mumbai	Bowl	Won	126	96	7.88	6	10	76	33	51	9	0	0	2	126	7
56	Punjab			Won	221	120	11.05	14	20	164	39	45	7	0	6	2	213	1
	Rajasthan	Rajasthan	Bowl	Lost	180	120	9.00	8	18	120	40	47	3	0	5	3	121	4
57	Rajasthan			Won	192	120	9.60	10	19	136	36	50	9	0	5	3	134	3
	Delhi	Delhi	Bowl	Lost	87	97	5.44	1	9	42	34	54	10	0	4	1	27	3
58	Chennai			Won	116	89	7.73	4	13	76	34	41	8	1	4	1	102	2
	Punjab	Punjab	Bat	Lost	112	120	5.60	2	11	56	35	66	1	0	6	1	35	4
59	Rajasthan	Rajasthan	Bowl	Won	164	120	8.20	5	12	78	45	51	5	0	8	2	97	4
	Chennai			Lost	163	120	8.15	7	9	78	48	44	7	1	4	4	128	6
				Mean	156	113	8.32	5.4	14.9	92	40.6	49.9	6.0	0.16	4.4	2.3	114	4.7
				SD	33	13	1.54	3.1	4.3	28	9.0	10.3	2.7	0.37	2.4	1.0	45	2.3

Study 2: IPL game statistics – Part 2.

Game	Team	Bowling changes (fielding)	Opening partnership	First 6 overs	Runs made	Wickets lost	4's hit	6's hit	Middle 8 overs	Runs made	Wickets lost	4's hit	6's hit	Last 6 overs	Runs made	Wickets lost	4's hit	6's hit
1	Bangalore	6	4		64	1	5	5		66	2	4	2		92	1	4	8
	Kolkata	5	61		26	4	1	1		51	5	3	2		5	1	0	0
2	Punjab	7	56		53	1	9	1		90	3	4	7		97	1	7	8
	Chennai	5	26		63	1	7	3		89	1	8	4		55	2	3	2
3	Delhi	5	20		40	2	5	1		47	4	3	1		42	2	5	1
	Rajasthan	6	17		55	1	10	1		60	0	5	0		17	0	3	0
4	Kolkata	6	6		39	2	2	2		26	3	2	0		45	5	2	4
	Deccan	6	21		26	3	3	0		51	1	1	2		35	1	2	2
5	Mumbai	6	9		40	1	6	0		69	3	5	3		57	1	4	3
	Bangalore	6	37		47	2	8	1		52	1	5	1		66	3	6	3
6	Rajasthan	7	6		54	1	8	3		58	3	6	1		54	4	4	3
	Punjab	6	34		53	3	6	2		74	1	6	4		41	0	4	1
7	Deccan	6	9		48	1	8	0		94	0	7	5					
	Delhi	5	31		24	2	2	1		43	3	5	0		74	3	5	5
8	Chennai	5	34		52	2	7	1		78	2	6	2		72	3	6	5
	Mumbai	8	9		53	2	8	1		84	0	6	4		71	3	10	1
9	Deccan	6	22		73	1	8	5		66	2	5	3		78	4	5	6
	Rajasthan	7	14		58	2	11	1		71	1	2	5		85	2	11	3
10	Punjab	5	8		39	2	5	1		59	5	5	3		18	2	2	0
	Mumbai	6	14		60	1	8	1		62	3	3	2		60	6	7	2
11	Chennai	5	66		61	3	8	3		31	2	1	0		55	4	5	1
	Kolkata	7	32		45	0	7	0		62	1	2	3		45	0	3	2
12	Bangalore	6	1		45	2	8	0		72	0	10	2		21	1	4	0
	Rajasthan	6	1		57	2	8	3		33	5	0	2		45	1	4	2
13	Punjab	6	2		45	3	7	0		53	2	5	1		60	3	6	1
	Delhi	6	11		55	2	10	0		64	2	5	2		43	2	4	1
14	Mumbai	7	15		60	0	9	2		95	0	4	9		0	0	0	0
	Deccan	6	155		26	3	4	0		57	2	6	1		70	3	4	3
15	Bangalore	5	13		36	1	5	0		58	2	1	4		84	2	11	5
	Chennai	5	22		45	1	4	2		82	1	7	3		38	8	3	0
16	Kolkata	7	5		38	3	7	1		64	0	6	1		36	0	4	0
	Mumbai	6	16		40	3	6	1		37	3	4	0		60	2	4	2

Game	Team	Bowling changes (fielding)	Opening partnership	First 6 overs	Runs made	Wickets lost	4's hit	6's hit	Middle 8 overs	Runs made	Wickets lost	4's hit	6's hit	Last 6 overs	Runs made	Wickets lost	4's hit	6's hit
17	Delhi	7	53		55	3	5	3		75	0	7	2		51	2	4	2
	Bangalore	7	6		58	1	9	1		80	0	7	3		53	4	5	1
18	Rajasthan	6	11		51	2	5	1		69	1	2	4		31	6	1	1
	Kolkata	7	15		45	1	6	1		86	3	13	1		65	3	3	3
19	Deccan	6	27		41	1	6	0		69	2	10	0		57	0	5	2
	Punjab	5	41		50	1	8	0		48	4	3	1		66	3	9	2
20	Chennai	5	23		64	0	7	3		70	1	5	2		38	1	4	0
	Delhi	7	115		47	1	7	0		72	1	7	2		50	4	3	3
21	Bangalore	5	13		33	2	5	0		72	0	8	2		48	4	2	3
	Deccan	6	22		46	1	6	0		64	3	4	2		46	4	4	2
22	Punjab	6	28		31	4	3	1		54	1	4	1		84	1	2	7
	Kolkata	6	22		49	1	9	0		62	4	5	3		67	1	8	1
23	Mumbai	7	46		37	2	3	2		72	2	6	2		24	6	0	1
	Delhi	7	3		50	2	8	1		60	2	2	4		52	4	4	3
24	Rajasthan	6	78		38	4	6	0		49	1	4	1		22	5	2	0
	Chennai	6	0		44	0	8	0		64	2	2	2		2	0	0	0
25	Bangalore	5	1		52	1	5	2		51	2	6	0		24	1	1	1
	Punjab	6	11		26	3	4	0		58	1	6	0		42	6	6	1
26	Chennai	5	4		50	1	5	3		62	1	8	1		36	1	2	3
	Deccan	6	24		34	3	4	0		50	2	5	0		60	2	2	5
27	Mumbai	6	41		48	2	5	2		47	4	3	0		8	4	1	0
	Rajasthan	5	12		34	0	0	2		57	3	6	1		13	0	1	0
28	Delhi	6	45		62	0	9	1		76	3	8	3		50	3	3	1
	Chennai	6	62		50	2	7	0		69	0	5	2		68	3	10	1
29	Kolkata	6	9		35	2	6	0		61	1	5	1		28	1	4	1
	Bangalore	5	17		41	2	4	1		60	4	6	2		28	1	2	2
30	Rajasthan	6	109		50	0	8	1		50	3	3	1		150	5	4	1
	Deccan	7	61		50	0	5	2		64	1	7	0		27	1	4	0
31	Chennai	6	10		35	2	3	1		72	3	3	4		56	4	1	6
	Punjab	6	16		53	2	6	1		79	1	6	4		49	1	3	1
32	Deccan	7	12		43	1	8	0		65	1	7	2		96	2	7	6
	Kolkata	6	4		55	3	10	0		66	2	2	5		60	2	4	3

Game	Team	Bowling changes (fielding)	Opening partnership	First 6 overs	Runs made	Wickets lost	4's hit	6's hit	Middle 8 overs	Runs made	Wickets lost	4's hit	6's hit	Last 6 overs	Runs made	Wickets lost	4's hit	6's hit
33	Rajasthan	5	11		47	1	6	0		47	3	1	0		62	2	3	5
	Delhi	6	47		21	2	1	0		84	2	7	3		54	3	5	3
34	Punjab	6	42		49	3	7	1		47	1	3	0		46	4	3	1
	Bangalore	6	4		42	0	1	3		81	1	7	4		21	0	4	0
35	Kolkata	6	35		37	4	6	0		54	2	7	0		19	4	0	0
	Delhi	6	2		35	1	5	0		56	2	4	0		42	3	1	2
36	Mumbai	6	82		28	2	4	0		49	4	6	0		73	2	8	3
	Chennai	6	18		78	0	4	8		80	1	8	4					
37	Delhi	5	7		71	5	3	4		49	3	3	2		62	5	5	3
	Deccan	7	21		48	1	4	2		82	0	10	1		64	3	4	3
38	Mumbai	5	6		27	3	2	1		38	5	5	0		2	2	0	0
	Kolkata	3	16		68	2	9	3										
39	Rajasthan	7	109		23	3	3	0		50	4	3	1		59	2	4	5
	Bangalore	6	0		51	0	6	1		75	1	7	1		71	0	8	1
42	Deccan	6	7		57	1	9	2		47	3	3	0		74	3	5	4
	Mumbai	7	39		32	3	5	0		60	1	6	1		61	3	2	5
43	Bangalore	6	31		71	0	12	0		52	3	4	1		35	2	3	2
	Delhi	6	90		41	1	4	1		56	2	6	1		57	4	3	4
44	Kolkata	6	7		42	3	6	1		71	1	6	3		37	0	5	1
	Rajasthan	6	16		32	1	5	0		61	2	5	3		54	5	3	3
45	Mumbai	6	36		43	1	4	2		82	0	8	3		64	3	6	3
	Punjab	6	1		68	1	7	3		66	2	6	2		54	7	4	1
46	Chennai	5	60		22	2	3	0		42	2	3	0		61	4	8	1
	Bangalore	6	7		44	0	5	1		42	4	2	1		25	4	3	0
48	Punjab	6	84		42	0	7	0		67	1	2	5		66	3	5	4
	Deccan	6	79		74	0	7	5		49	2	4	0		55	2	1	4
49	Chennai	6	14		67	0	9	2		83	2	5	5		61	3	6	2
	Rajasthan	6	127		65	1	8	4		79	1	6	3		57	5	5	2
50	Delhi	5	20		60	0	8	3		54	3	3	2		62	5	7	2
	Mumbai	6	70		56	2	7	3		64	2	6	1		59	1	7	2
51	Deccan	7	101		43	1	8	0		60	2	3	3		68	2	8	4
	Bangalore	6	20		41	0	4	0		76	2	7	5		48	7	4	3
52	Kolkata	6	45		47	1	6	0		74	1	5	4		53	4	6	1
	Punjab	6	24		51	2	9	1		45	2	4	1		79	3	4	7
53	Rajasthan	6	20		29	0	2	0		63	2	6	0		53	5	6	1
	Mumbai	7	71		36	2	5	0		49	3	4	0		61	0	2	2

Game	Team	Bowling changes (fielding)	Opening partnership	First 6 overs	Runs made	Wickets lost	4's hit	6's hit	Middle 8 overs	Runs made	Wickets lost	4's hit	6's hit	Last 6 overs	Runs made	Wickets lost	4's hit	6's hit
54	Deccan	6	11		44	1	8	0		64	1	6	2		40	0	2	1
	Chennai	5	26		26	2	3	0		59	1	4	1		62	5	6	2
55	Bangalore	5	35		39	0	2	1		71	1	5	5		16	0	1	0
	Mumbai	5	96		36	2	4	0		48	5	4	1		38	2	3	1
56	Punjab	7	133		38	2	7	0		94	2	5	7		48	3	6	1
	Rajasthan	6	5		51	0	9	1		84	1	8	4		86	2	3	9
57	Rajasthan	6	65		28	3	2	0		51	5	6	1		8	1	1	0
	Delhi	5	10		58	0	10	1		72	4	5	4		62	5	4	5
58	Chennai	5	14		35	4	3	1		28	3	2	0		49	1	6	1
	Punjab	6	8		35	1	6	0		65	0	5	3		16	0	2	1
59	Rajasthan	6	19		42	1	4	1		67	2	2	4		54	2	3	2
	Chennai	5	39		36	1	5	0		66	2	5	2		57	4	2	3
	Mean	5.9	31.7		45.8	1.6	5.9	1.1		62.6	2.0	4.9	2.1		50.7	2.6	4.0	2.3
	SD	0.7	32.5		12.6	1.2	2.4	1.4		14.5	1.3	2.2	1.8		23.2	1.8	2.4	2.0

Study 3: GPS validation

	Criterion Distance 8800 m						Criterion Distance 2400 m						Criterion Distance 1200 m				
Trial #	Max-A	Max-B	SPI-10	SPI-A	SPI-B		Max-A	Max-B	SPI-10	SPI-A	SPI-B		Max-A	Max-B	SPI-10	SPI-A	SPI-B
1	9845	9187	8874	8715	8754		2407	2450	2402	2197	2380		1172	1200	1184	1178	1189
2	8710	8897	8783	8716	8735		2329	2390	2384	2042	2376		1197	1265	1181	1180	1189
3	8683	9036	8717	8760	8768		2347	2386	2350	2180	2329		1186	1215	1178	1179	1193
4	9263	8851	8676	8618	8649		2419	2436	2362	2317	2380		1194	1224	1178	1178	1185
5	9044	9048	8705	8716	8639		2572	2431	2366	2348	2369		1196	1222	1182	1175	1185
6	8852	9157	8743	8757	8783		2523	2451	2380	2362	2352		1189	1213	1180	1170	1169
7	8889	9274	8802	8687	8698		2402	2484	2370	2385	2364		1205	1332	1192	1079	1180
8	9002	9164	8755	8755	8753		2356	2486	2366	2370	2297		1212	1222	1199	1082	1183
9	8818	9325	8725	8772	8765		2350	2370	2385	2364	2356		1221	1228	1186	1152	1160
10	8777	8982	8716	8391	8729		2361	2502	2390	2390	2370		1197	1236	1180	1164	1191
11	8661	9244	8703	8742	8715		2347	2364	2382	2332	2346		1249	1263	1195	1146	1191
12	8728	9062	8649	8784	8759		2374	2396	2391	2374	2258		1266	1255	1196	1161	1185
13	8801	8869	8768	8669	8765		2444	2415	2380	2367	2309		1252	1261	1193	1144	1188
14	9088	9125	8702	8668	8750		2439	2397	2369	2365	2334		1120	1164	1190	1145	1183
15	9846	8600	8701	8635	8668		2404	2401	2390	2373	2330		1239	1205	1154	1145	1183
16	8977	9164	8724	8659	8746		2366	2426	2383	2380	2259		1240	1246	1286	1165	1191
17	9069	9323	8722	8719	8766		2355	2413	2368	2385	2332		1177	1219	1189	1155	1188
18	8778	9221	8657	8752	8724		2407	2451	2381	2377	2327		1181	1181	1165	1151	1194
19	8791	9032	8728	8731	8678		2464	2384	2370	2380	2325		1196	1219	1172	1171	1191
20	9011	9067	8734	8743	8758		2457	2343	2378	2380	2317		1202	1245	1171	1176	1183
Mean	**8981.7**	**9081.4**	**8729.2**	**8699.5**	**8730.1**		**2406.2**	**2418.8**	**2377.4**	**2333.4**	**2335.5**		**1204.6**	**1230.8**	**1187.6**	**1154.7**	**1185.1**
SD	334.9	179.6	50.9	86.1	42.4		63.1	42.8	12.1	89.7	35.7		33.4	35.6	25.7	28.5	8.1

	Criterion distance 600m					Criterion distance 20m				Criterion distance 30m			
Trial #	Max-A	Max-B	SPI-10	SPI-A	SPI-B	Max-A	Max-B	SPI-A	SPI-B	Max-A	Max-B	SPI-A	SPI-B
1	592	621	600	595	597	11.4	15.0	15.3	18.9	20.9	24.0	24.3	28.9
2	597	613	593	591	590	11.9	20.1	15.0	15.4	22.6	31.1	26.9	25.3
3	600	600	591	591	594	11.3	16.0	17.3	15.2	20.0	21.4	28.0	24.7
4	597	614	594	587	595	16.2	18.1	17.5	16.8	26.0	28.9	27.3	25.8
5	609	614	585	582	594	9.8	20.6	18.4	16.3	20.3	30.5	28.3	25.5
6	617	592	588	575	594	13.7	6.6	18.1	17.4	24.1	13.8	27.9	26.4
7	588	611	586	593	592	14.8	19.6	16.6	17.4	24.7	22.7	25.3	26.8
8	608	594	591	590	595	11.8	17.3	17.5	18.4	22.5	26.4	27.9	27.7
9	577	596	591	581	591	14.5	9.3	15.2	16.9	20.0	19.8	25.3	26.8
10	595	586	585	563	594	16.2	10.3	17.0	16.3	26.0	21.8	25.7	25.8
11	621	595	586	559	590	8.1	13.5	15.2	18.0	17.5	23.0	25.5	27.4
12	608	607	590	522	592	11.8	7.1	17.9	19.0	19.2	12.7	28.0	28.7
13	611	588	596	594	597	13.3	19.2	16.5	18.2	23.3	26.1	26.6	26.7
14	610	606	584	595	596	11.0	8.0	17.8	17.6	16.7	17.7	27.9	27.9
15	605	605	589	596	597	14.5	13.1	17.1	11.7	26.6	15.7	26.0	20.7
16	605	589	594	595	593	7.1	20.4	16.8	18.1	14.8	32.0	27.2	26.5
17	594	599	582	595	595	9.3	13.3	18.5	16.8	19.0	23.3	28.9	25.2
18	597	591	588	595	596	9.3	16.0	16.2	18.0	13.8	25.0	25.9	25.3
19	595	601	594	590	594	17.7	19.7	18.0	22.9	28.2	30.3	28.1	32.8
20	608	583	588	588	593	17.2	19.7	16.9	16.3	29.3	31.5	27.1	25.9
Mean	**601.7**	**600.3**	**589.8**	**583.9**	**594.0**	**12.5**	**15.1**	**16.9**	**17.3**	**21.8**	**23.9**	**26.9**	**26.5**
SD	10.4	10.8	4.5	18.0	2.2	3.0	4.8	1.1	2.1	4.3	5.9	1.3	2.3

Criterion distance 40m						Run-a-Three						
Trial #	Max-A	Max-B	SPI-A	SPI-B		Distance (m)	Max-A	Max-B	Distance (m)	SPI-A	Distance (m)	SPI-B
1	26.7	33.2	35.8	38.7		50.5	26.4	36.9	50.9	42.6	50.8	48.1
2	32.2	39.8	37.2	35.6		50.5	29.7	40.2	50.8	35.9	50.6	50.1
3	28.8	32.2	38.4	35.8		50.3	44.8	36.1	50.8	38.5	50.5	48.3
4	36.4	39.1	37.1	36.1		50.4	31.3	38.8	50.8	40.6	50.6	46.6
5	30.5	37.3	38.3	36.2		50.4	42.3	38.3	50.7	44.0	50.7	48.0
6	29.5	23.7	37.6	36.6		50.4	42.6	32.4	50.9	35.6	50.7	46.4
7	35.1	29.6	35.6	36.5		50.4	39.0	38.6	50.8	39.6	50.7	48.0
8	30.1	32.9	38.1	38.7		50.4	41.8	34.9	50.8	36.1	50.7	48.7
9	29.3	27.7	35.7	38.2		50.3	47.2	35.7	50.7	37.3	50.7	48.3
10	38.1	29.3	36.1	36.3		50.3	42.7	43.1	50.6	43.8	50.6	46.8
11	28.9	34.6	34.6	36.9		51.1	35.3	37.3	51.2	34.2	50.6	44.8
12	22.1	17.9	38.2	39.9		51.2	30.9	34.1	50.9	43.1	50.6	46.6
13	33.2	30.4	35.3	37.2		50.8	28.6	36.6	50.9	44.9	50.8	46.6
14	26.4	28.0	37.9	37.1		50.8	35.2	32.8	50.6	44.4	50.5	46.3
15	35.4	20.3	36.4	30.6		50.8	29.3	35.2	50.9	43.5	50.8	49.7
16	20.3	39.0	37.4	37.6		50.6	37.5	33.0	51.0	43.3	50.6	49.3
17	27.5	34.7	37.8	35.7		50.9	33.9	35.5	51.0	44.1	50.7	48.3
18	18.3	35.0	35.8	33.3		50.9	39.2	37.1	50.9	41.8	50.7	45.8
19	39.1	39.5	38.1	47.1		50.9	26.9	36.2	50.9	40.1	50.6	46.9
20	39.5	39.7	37.3	36.5		50.9	35.3	34.5	51.0	40.4	50.7	47.7
Mean	**30.4**	**32.2**	**36.9**	**37.0**		**50.6**	**36.0**	**36.4**	**50.9**	**40.7**	**50.7**	**47.6**
SD	6.0	6.4	1.2	3.1		0.3	6.3	2.6	0.1	3.4	0.1	1.4

Time-of-Day Trials											
	MinimaxX unit number #										
	1	2	3	4	5	6	7	8	9		
Am											
1	1214	1156	1163	1171	1189	1197	1197	1203	1209		
2	1225	1169	1175	1183	1189	1198	1192	1200	1214		
3	1221	1162	1156	1149	1186	1186	1191	1195	1207		
											Am Overall
Mean	**1220.0**	**1162.3**	**1164.7**	**1164.7**	**1188.0**	**1193.7**	**1193.3**	**1199.3**	**1210.0**		**1188.8**
SD	5.6	6.5	9.6	17.2	1.7	6.7	3.2	4.0	3.6		20.6
	1	2	3	4	5	6	7	8	9		
Pm											
1	1230	1190	1186	1201	1201	1200	1188	1196	1235		
2	1244	1174	1167	1188	1199	1209	1206	1215	1224		
3	1260	1235	1183	1215	1205	1218	1210	1210	1229		
											Pm Overall
Mean	**1244.7**	**1199.7**	**1178.7**	**1201.3**	**1201.7**	**1209.0**	**1201.3**	**1207.0**	**1229.3**		**1208.1**
SD	15.0	31.6	10.2	13.5	3.1	9.0	11.7	9.8	5.5		21.8

Study 4: ODI Fast bowler case study

Raw data		Distance (m) covered						Time (s) spent	
Date	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
08/10/2007	227	11696	1597	461	639	1322	15715	13123	508
11/10/2007	195	7104	1215	361	562	1258	10500	11255	474
14/10/2007	228	11583	1781	418	730	981	15493	13226	430
17/10/2007	215	16600	1723	444	796	1095	20658	12410	494
14/12/2007	226	9124	2622	574	753	1678	14751	12909	634
03/02/2008	213	11439	2327	661	888	1101	16416	12213	558
08/02/2008	147	8266	2670	539	723	998	13196	8328	468
10/02/2008	202	11648	2801	552	821	1181	17003	11583	561
22/02/2008	129	7333	2371	396	583	620	11303	7387	323
30/08/2008	126	6067	1970	491	575	634	9737	7196	359
03/09/2008	162	7747	1539	367	475	486	10614	9216	279
06/09/2008	137	6428	2075	402	620	740	10265	7843	368
Mean	**184**	**9586**	**2058**	**472**	**680**	**1008**	**13804**	**10557**	**455**
SD	41	3079	505	93	124	343	3414	2382	106

Raw data	Sprint data						High Intensity Effort data	
Date	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
08/10/2007	227	73	19	43	7.9		180	2.8
11/10/2007	195	63	22	76	7.1		172	2.8
14/10/2007	228	57	17	32	8.7		155	2.8
17/10/2007	215	76	15	44	9.1		180	2.7
14/12/2007	226	82	21	63	8.9		209	3.0
03/02/2008	213	62	18	53	8.3		193	2.9
08/02/2008	147	58	18	89	8.6		170	2.8
10/02/2008	202	68	20	82	7.6		203	2.8
22/02/2008	129	42	14	30	9.3		132	2.4
30/08/2008	126	36	18	50	9.6		130	2.8
03/09/2008	162	34	13	29	6.4		107	2.6
06/09/2008	137	46	16	60	8.5		142	2.6
Mean	184	58	18	54	8.3		164	2.7
SD	41	16	3	20	0.9		32	0.1

Study 5: State T20

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
Batsmen									
AB	31	1721	443	67	143	231	2605	1770	89
TC	39	2228	606	124	185	228	3371	2229	110
GB	17	511	249	45	86	84	975	974	45
AB	19	1231	146	36	32	50	1495	1115	24
LD	21	1647	361	53	111	89	2261	1163	41
GB	15	530	224	73	170	152	1149	814	85
Mean	**23.7**	**1311**	**338**	**66**	**121**	**139**	**1976**	**1344**	**66**
SD	9.4	689	168	31	57	78	932	542	34
Fast bowlers									
BL	75	3132	2038	546	941	895	7552	3998	499
JH	75	3714	1246	278	321	620	6179	4238	259
BE	75	5100	2575	596	539	524	9334	4133	364
BL	75	4133	2372	675	917	671	8768	4005	493
Mean	**75**	**4020**	**2058**	**524**	**680**	**678**	**7958**	**4094**	**404**
SD	0	829	585	172	302	157	1400	115	115

Raw data			Sprint data				High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Batsmen								
AB	31	17	14	48	7.2		42	2.1
TC	39	16	14	41	9.7		47	2.3
GB	17	7	10	18	6.9		24	1.9
AB	19	3	16	29	7.6		12	2.0
LD	21	6	11	19	7.2		20	2.1
GB	15	10	16	43	7.0		36	2.4
Mean	**23.7**	**10**	**14**	**33**	**7.6**		**30**	**2.1**
SD	9.4	6	3	13	1.1		14	0.2
Fast bowlers								
BL	75	48	17	79	8.2		183	2.7
JH	75	33	20	32	9.6		99	2.6
BE	75	34	15	43	9.0		141	2.6
BL	75	43	15	48	9.4		187	2.6
MEAN	**75**	**40**	**17**	**51**	**9.1**		**153**	**2.6**
SD	0	7	2	20	0.6		41	0.1

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
Fielders									
AF	75	4301	1778	438	521	685	7723	4133	352
AB	75	3828	2755	762	1094	1240	9679	3809	587
MK	75	4612	1806	420	368	336	7542	3634	242
RQ	75	4018	2318	564	606	332	7838	4063	333
TC	75	5342	1830	452	485	453	8562	4035	296
GB	75	3158	2027	479	704	536	6904	4100	397
NR	75	3226	1071	166	260	157	4880	4347	150
RQ	75	2633	1831	631	1083	720	6898	3950	536
AV	75	4320	2266	470	415	434	7905	4220	277
AB	67	3070	1476	763	1430	988	7727	3314	686
LD	75	5924	1779	218	197	316	8434	4356	129
CP	75	5092	2039	306	390	242	8069	4291	205
GB	75	3786	2445	538	692	591	8052	4114	382
TC	67	3412	1078	257	251	111	5109	3872	142
Mean	**74**	**4052**	**1893**	**462**	**607**	**510**	**7523**	**4017**	**337**
SD	3	948	477	184	365	317	1272	288	170

Raw data			Sprint data				High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fielders								
AF	75	36	20	63	8.5		131	2.7
AB	75	75	15	45	8.9		227	2.6
MK	75	22	16	53	8.2		105	2.3
RQ	75	23	15	62	9.4		120	2.8
TC	75	26	17	61	8.4		99	3.0
GB	75	38	15	44	9.6		170	2.3
NR	75	12	17	35	6.8		54	2.8
RQ	75	32	24	95	9.0		139	3.9
AV	75	27	15	35	8.7		104	2.7
AB	67	42	22	103	8.8		189	3.6
LD	75	14	21	54	10.9		53	2.4
CP	75	20	11	26	7.3		84	2.4
GB	75	26	21	52	8.9		135	2.8
TC	67	8	13	26	6.9		61	2.3
MEAN	**74**	**29**	**17**	**54**	**8.6**		**119**	**2.8**
SD	3	17	4	23	1.1		51	0.5

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
Spin bowlers									
CW	75	6548	1112	125	116	49	7950	4433	62
AH	75	6341	2094	349	467	298	9549	3971	238
MN	75	4932	1371	131	93	85	6612	4421	76
Mean	**75**	**5940**	**1526**	**202**	**225**	**144**	**8037**	**4275**	**125**
SD	0	879	509	128	210	135	1470	263	98
Wicketkeepers									
GM	75	4955	1387	252	155	105	6854	4380	118
LR	75	4198	1120	152	143	31	5644	4416	79
GM	67	3557	1030	198	180	34	4999	3915	103
Mean	**72**	**4237**	**1179**	**201**	**159**	**57**	**5832**	**4237**	**100**
SD	5	700	186	50	19	42	942	279	20

Raw data			Sprint data				High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Spin bowlers								
CW	75	5	10	21	7.1		32	1.9
AH	75	18	18	56	11.0		90	2.6
MN	75	5	18	37	8.5		36	2.1
Mean	**75**	**9**	**15**	**38**	**8.9**		**53**	**2.2**
SD	0	8	5	18	2.0		32	0.4
Wicketkeepers								
GM	75	7	13	33	6.7		53	2.2
LR	75	3	10	14	5.7		34	2.3
GM	67	4	8	14	7.0		47	2.2
Mean	**72**	**5**	**10**	**20**	**6.5**		**45**	**2.2**
SD	5	2	3	11	0.7		10	0.1

Twenty20

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Batsmen											
AF	34	599	140	48	69	18	874			2008	33
CP	23	726	131	30	69	87	1043			1339	44
MH	20	343	66	20	40	21	490			1176	22
AF	34	599	140	48	69	18	874			2008	33
CP	23	726	131	30	69	87	1043			1339	44
MH	36	739	124	30	108	117	1118			2124	50
PH	50	1341	217	51	154	52	1815			2922	64
BC	27	935	211	80	158	127	1511			1547	79
DW	33	831	177	41	91	102	1242			1940	52
JH	20	500	110	50	112	61	833			1136	49
LD	23	724	78	25	69	59	955			1349	31
MH	27	897	126	25	66	76	1190			1555	35
MH	44	984	199	57	84	101	1425	117	149	2573	51
PF	37	1218	180	36	55	122	1611	143	182	2176	44
SO	32	1067	277	71	98	119	1632	161	198	1870	57
TD	29	972	191	34	62	71	1330	136	177	1674	34
DW	56	1495	331	102	131	109	2168	148	185	3282	197
GM	64	1500	288	89	241	176	2294	148	187	3702	111
LD	21	708	180	54	86	73	1101	138	174	1238	49
UK	42	1101	180	58	150	97	1586	150	179	2477	68
VK	24	741	232	53	78	47	1151	139	174	1396	44
MH	43	1203	286	71	222	344	2126	176	199	2450	127
PF	60	1825	381	127	148	87	2568	169	198	3517	83
UK	29	868	128	58	99	104	1257	175	200	1686	54
LD	29.5	453	203	55	59	72	842			1730	39
PF	40	1224	178	89	189	237	1917			2296	103
Mean	35	935	188	55	107	99	1384	150	184	2020	61
SD	*12*	*355*	*76*	*26*	*53*	*69*	*516*	*18*	*15*	*720*	*38*

Twenty20

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Batsmen								
AF	34	2	11	18			21	1.6
CP	23	9	11	23			23	1.9
MH	20	3	10	12	4.6		14	1.6
AF	34	2	11	18	5.0		21	1.6
CP	23	9	11	23	5.3		23	1.9
MH	36	8	13	28	7.8		22	2.3
PH	50	5	9	18	5.2		41	1.6
BC	27	10	13	17	5.2		34	2.3
DW	33	9	11	27	6.2		20	2.6
JH	20	3	20	9	4.1		19	2.6
LD	23	6	10	17	5.3		13	2.4
MH	27	4	19	38	7.9		13	2.7
MH	44	7	14	23	5.9		17	3.0
PF	37	10	12	18	4.7		16	2.8
SO	32	5	24	12	4.5		20	2.9
TD	29	7	10	15	5.3		13	2.6
DW	56	7	16	25	6.2		28	7.0
GM	64	10	18	21	5.9		46	2.4
LD	21	7	10	15	4.7		20	2.5
UK	42	7	14	17	5.4		24	2.8
VK	24	5	9	10	4.5		16	2.8
MH	43	30	11	20	5.3		55	2.3
PF	60	8	11	16	5.6		34	2.4
UK	29	12	9	21	5.5		26	2.1
LD	29.5	6	11	14	6.3		21	1.9
PF	40	23	10	22	7.1		52	2.0
Mean	**35**	**8**	**13**	**19**	**5.6**		**25**	**2.5**
SD	12	6	4	6	1.0		12	1.0

Twenty20

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fast bowlers											
BC	37.5	1783	465	138	258	496	3140			2070	182
GS	40	2302	315	97	212	710	3636			2198	189
BC	88	3754	789	218	355	617	5733			5031	248
GS	88	3752	829	160	237	494	5472	145	183	5094	177
MH	82	3694	567	112	187	450	5010	129	186	4773	155
PS	91	3256	785	111	85	58	4295	124	173	5397	60
T	92	3678	831	171	170	530	5380	115	157	5341	173
TD	84	3735	1284	236	419	514	6188	135	186	4802	261
DK	80	3465	705	116	172	591	5049	124	180	4608	166
PS	80	3187	640	141	249	662	4879	125	176	4593	206
AR	69	3008	1744	429	627	300	6108			3831	309
GS	90	4201	1028	223	334	788	6574			4541	260
MH	90	3882	1020	223	348	640	6113	144	191	5048	252
SV	54.5	2268	635	159	240	378	3680	150	186	3120	156
TD	90	4170	1687	413	541	461	7272	143	193	5072	326
BC	78	3506	1285	250	345	482	5868			4448	230
JS	78	3123	1031	320	469	325	5268			4437	240
MH	78	3519	942	174	240	154	5029			4551	127
Mean	**77**	3349	921	205	305	481	5261	133	181	4386	207
SD	*17*	*659*	*385*	*98*	*140*	*187*	*1074*	*12*	*10*	*979*	*66*

Twenty20

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fast bowlers								
BC	37.5	28	18	25	5.9		78	2.3
GS	40	28	25	40	8.0		55	3.4
BC	88	36	17	29	6.6		84	3.0
GS	88	30	16	29	6.4		65	2.7
MH	82	25	18	54	6.5		52	3.0
PS	91	4	15	25	5.8		20	3.0
T	92	29	18	28	6.0		60	2.9
TD	84	37	14	28	6.2		103	2.5
DK	80	29	20	68	6.7		56	3.0
PS	80	31	21	31	7.0		67	3.1
AR	69	22	14	24	5.9		110	2.8
GS	90	37	21	46	6.5		86	3.0
MH	90	37	17	38	7.7		92	2.7
SV	54.5	19	20	52	6.3		54	2.9
TD	90	30	15	40	7.0		109	3.0
BC	78	36	13	29	8.5		96	2.4
JS	78	27	12	21	7.1		101	2.4
MH	78	13	12	21	7.4		55	2.3
Mean	**77**	**28**	**17**	**35**	**6.8**		**75**	**2.8**
SD	*17*	9	4	13	0.8		25	0.3

Twenty20

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fielders											
AF	81	3175	939	322	496	401	5333			4585	268
CP	48	2488	544	120	156	83	3391			2780	85
EC	43	672	390	72	142	152	1428			2503	83
MC	88	3199	963	247	275	133	4817			5151	152
MH	79	3292	845	146	153	49	4485			4641	94
EC	83	3401	1319	336	440	157	5653			4725	241
MH	83	2966	1032	267	237	239	4741			4795	175
DW	81	3103	1128	173	161	109	4674			4762	103
LP	79	2522	745	174	201	61	3703			4641	115
MW	74	2447	910	107	171	134	3769			4351	102
MH	79	3913	1026	290	483	265	5977			4496	233
PH	80	3610	1275	161	165	43	5254			4720	104
PF	31	1349	457	108	123	110	2147	125	160	1772	78
VK	90	3059	378	47	50	94	3628	95	144	5362	38
LD	78	2313	646	106	88	50	3203	107	149	4621	60
MH	68	3246	817	95	108	72	4338			4013	66
PF	64	2126	488	124	162	200	3100	102	161	3741	119
T	51	1573	426	65	43	60	2167			2992	38
VK	75	2368	454	89	83	91	3085	94	147	4445	55
DW	87	2628	1258	319	297	162	4664			5039	181
LD	90	3464	1616	364	345	323	6112	138	179	5166	235
MW	90	3431	1667	419	592	574	6683			5024	351
UK	53	1950	849	223	208	86	3316	141	174	3058	121
LD	78	2803	1074	144	119	25	4165			4609	68
PF	78	3487	1318	337	383	314	5839			4452	220
SO	78	2922	1093	190	157	114	4476			4575	102
Mean	**73**	**2750**	**910**	**194**	**225**	**158**	**4236**	**115**	**159**	**4270**	**134**
SD	*16*	*762*	*370*	*107*	*147*	*128*	*1313*	*20*	*14*	*910*	*80*

Twenty20

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fielders								
AF	81	21	19	50	7.7		103	2.6
CP	48	7	12	28	5.6		37	2.3
EC	43	9	18	49	5.6		33	2.5
MC	88	9	14	40	8.2		48	3.2
MH	79	5	10	16	5.1		41	2.3
EC	83	11	16	39	6.7		98	2.5
MH	83	16	15	33	7.4		72	2.4
DW	81	10	9	14	6.2		40	2.6
LP	79	4	15	32	5.4		52	2.2
MW	74	11	13	22	5.6		48	2.1
MH	79	16	16	32	7.9		86	2.7
PH	80	4	15	30	6.0		50	2.1
PF	31	9	12	16	5.5		32	2.4
VK	90	4	24	33	6.7		11	3.5
LD	78	3	17	23	5.7		22	2.7
MH	68	6	12	14	4.8		23	2.9
PF	64	14	14	25	5.9		47	2.5
T	51	3	20	35	7.2		16	2.4
VK	75	4	23	28	6.4		18	3.1
DW	87	9	18	28	6.2		59	3.1
LD	90	18	18	41	7.2		86	2.7
MW	90	28	21	42	6.8		119	2.9
UK	53	5	17	25	5.8		38	3.2
LD	78	2	8	11	6.4		28	2.4
PF	78	22	13	79	7.3		96	2.3
SO	78	10	11	17	7.5		47	2.2
Mean	**73**	**10**	**15**	**31**	**6.4**		**52**	**2.6**
SD	*16*	*7*	*4*	*14*	*0.9*		*30*	*0.4*

Twenty20

Raw data	Distance (m) covered							Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Spin bowlers											
AH	45	2083	644	82	87	100	2996			2642	58
CB	87	3497	726	203	315	256	4997			5051	188
JH	32	1070	574	91	73	64	1872			1833	54
SO	90	3889	853	97	115	85	5039	136	174	5331	76
DW	81	2537	802	95	69	51	3554			4807	52
JH	67	2549	492	57	43	18	3159			3982	27
SS	60	2113	439	90	109	43	2794			3525	61
UK	62	2295	798	125	98	125	3441	129	167	3641	79
SO	90	3894	1284	231	242	127	5778	141	186	5260	139
UK	78	2981	880	132	111	27	4131			4611	66
Mean	**69**	**2691**	**749**	**120**	**126**	**90**	**3776**	**135**	**176**	**4068**	**80**
SD	*20*	*891*	*241*	*55*	*85*	*70*	*1200*	*6*	*10*	*1171*	*48*
Wicketkeepers											
GM	36	871	248	55	66	26	1266	127	154	2111	37
GM	80	2108	675	108	126	65	3082	122	162	4725	70
GM	89	2564	1091	358	349	128	4490	157	179	5150	189
Mean	**68**	**1848**	**671**	**174**	**180**	**73**	**2946**	**135**	**165**	**3995**	**99**
SD	*28*	*876*	*422*	*162*	*49*	*51*	*1616*	*19*	*13*	*1646*	*80*

Twenty20

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Spin bowlers								
AH	45	5	18	29	6.9		19	3.1
CB	87	19	13	42	6.4		59	3.2
JH	32	3	21	28	6.5		22	2.5
SO	90	5	17	27	6.1		23	3.3
DW	81	2	26	29	6.6		14	3.7
JH	67	2	9	8	3.8		10	2.7
SS	60	2	22	11	4.7		19	3.2
UK	62	9	14	24	6.0		29	2.7
SO	90	9	14	28	6.4		60	2.3
UK	78	3	9	13	6.3		32	2.1
Mean	**69**	**6**	**16**	**24**	**6.0**		**29**	**2.9**
SD	*20*	*5*	*5*	*10*	*1.0*		*17*	*0.5*
Wicketkeepers								
GM	36	2	13	7	4.6		12	3.1
GM	80	5	13	15	5.1		26	2.7
GM	89	10	13	19	5.5		75	2.5
Mean	**68**	**6**	**13**	**14**	**5.1**		**38**	**2.8**
SD	*28*	*4*	*0*	*6*	*0.5*		*33*	*0.3*

One Day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Batsmen											
LR	46.5	1524	116	45	57	106	1848			2749	42
AF	99	2702	269	95	185	225	3476			5852	102
DW	40	1006	210	76	106	71	1469			2353	67
CP	30	911	41	23	50	68	1093			1752	28
DW	36	477	100	35	54	30	696			2114	33
MH	20	510	51	27	69	103	760			1160	39
CP	41	1384	177	68	151	107	1887			2372	72
LR	60	1300	176	53	62	53	1644			3596	42
MH	90	3070	356	185	361	408	4380			5221	196
DW	46.5	1201	125	41	72	48	1487			2753	36
GM	73	1676	230	79	140	170	2295			4297	81
MW	129	4049	452	164	306	300	5271			7575	164
MH	46	991	153	34	63	108	1349			2718	42
PF	57	1940	312	84	223	449	3008	154	186	3275	144
GM	44	929	82	27	61	99	1198			2601	37
PF	126	3862	616	171	428	584	5661	140	188	7305	237
TD	114.5	3966	633	173	306	325	5403			6676	177
UK	21	561	44	13	44	8	670			1245	15
LD	102	1948	272	67	81	37	2405			3676	43
PF	47	1708	457	89	179	182	2615	130	165	2722	97
UK	154	4701	540	147	217	140	5744			9130	115
DW	97	2294	394	131	224	233	3276			5693	126
MH	22.5	790	92	23	48	54	1007			1323	27
MH	87	3036	522	187	364	330	4439			5034	182
MH	24	556	129	43	57	30	815			1407	31
MH	48	1990	386	109	281	207	2973			2758	120
PF	96	3482	668	221	342	300	5013			5573	183

Continued from previous table (One Day Batsmen)

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Batsmen											
BC	21	911	175	60	76	74	1296			1217	43
GM	60	1880	368	131	296	179	2854			3474	123
MH	70	2644	506	173	221	131	3675			4079	120
PF	46	1665	258	42	110	118	2193			2704	53
UK	20	626	110	50	33	0	819			1179	20
LD	51.2	1445	247	46	63	33	1834			3042	32
UK	148	4500	842	277	369	378	6366			8636	219
MH	100	3467	618	132	231	147	4595			5887	110
MH	98	3768	631	104	266	256	5025			5733	140
Mean	**66**	**2041**	**315**	**95**	**172**	**169**	**2793**	**141**	**180**	**3858**	**93**
SD	*38*	*1261*	*214*	*65*	*119*	*139*	*1729*	*12*	*13*	*2196*	*63*

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
Batsmen							
LR	46.5	7	14	30	8.0	18	2
AF	99	23	10	20	6.9	46	2
DW	40	6	17	44	7.6	36	2
CP	30	5	12	18	6.5	14	2
DW	36	3	12	13	4.7	20	2
MH	20	10	10	22	7.2	19	2
CP	41	10	9	14	6.6	32	2.3
LR	60	7	9	15	4.4	27	1.6
MH	90	39	9	17	6.8	91	2.2
DW	46.5	4	12	13	4.5	16	2.3
GM	73	11	15	18	5.1	31	2.6

Continued from previous table (One Day Batsmen)

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
MW	129	26	12	21	5.5		74	2.2
MH	46	8	14	31	6.4		16	2.6
PF	57	40	11	22	5.4		65	2.2
GM	44	8	12	23	5.7		15	2.5
PF	126	44	13	34	7.2		98	2.4
TD	114.5	27	12	31	6.3		72	2.5
UK	21	0	0	0	3.8		7	2.1
LD	102	4	9	10	4.1		19	2.3
PF	47	16	11	19	5.2		42	2.3
UK	154	13	11	12	4.7		49	2.3
DW	97	17	14	27	6.1		51	2.5
MH	22.5	5	11	16	4.7		10	2.7
MH	87	29	11	54	9.1		87	2.1
MH	24	2	14	18	8.9		15	2.1
MH	48	16	11	28	6.7		57	2.1
PF	96	23	12	27	6.7		90	2.0
BC	21	8	9	16	8.0		22	2.0
GM	60	18	9	18	6.5		65	1.9
MH	70	10	10	15	6.8		56	2.1
PF	46	10	11	22	8.0		26	2.0
UK	20	0	0	0	4.9		11	1.8
LD	51.2	2	10	11	5.5		16	2.0
UK	148	28	13	44	8.3		103	2.1
MH	100	13	10	19	6.6		57	1.9
MH	98	22	11	28	7.6		63	2.2
Mean	**66**	**14**	**11**	**21**	**6.3**		**43**	**2.2**
SD	*38*	*12*	*3*	*11*	*1.4*		*29*	*0.3*

One Day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fast bowlers											
BD	199	9437	2029	657	904	1933	14960			11258	679
SG	197	6688	3576	734	898	657	12553			11276	537
BC	200	10285	2514	632	723	769	14923			11327	470
BC	107	5108	1040	164	271	821	7404			6165	254
BD	160	7239	1152	327	502	1358	10578			9076	407
IC	155	6148	910	244	326	450	8078			9102	218
MH	160	6752	1285	356	399	985	9777			9229	377
BC	185	5347	984	312	647	1370	8660			6556	467
TD	179	8164	2506	677	940	718	13005			10212	519
TD	194	8290	2977	814	1135	756	13972			11034	605
JH	194	6896	1500	347	594	1206	10543			11182	444
MH	194	7413	2082	448	646	495	11084			11154	371
TD	194	5742	1540	365	402	452	8501			11337	279
MH	210	8741	2115	468	691	493	12508			12217	382
BC	173	7477	1774	490	628	669	11038			9990	384
PG	173	6438	1654	369	482	967	9910			10003	371
BC	210	9414	3705	927	1622	1474	17142			11714	877
MH	210	8323	1227	386	549	1150	11635			12192	398
BC	187	8465	2517	744	900	886	13512			10667	545
MH	187	6976	1101	183	343	1057	9660			10909	304
BC	189	8667	2500	706	793	898	13564			10830	502
BC	204	9533	2066	584	843	1262	14288			11696	531
TK	204	10076	1451	413	604	1526	14070			11764	467
BC	192	9360	2180	531	780	939	13790			10946	469
Mean	**186**	**7791**	**1933**	**495**	**693**	**970**	**11881**			**10493**	**452**
SD	*23*	*1493*	*781*	*205*	*297*	*382*	*2529*			*1548*	*142*

One Day

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fast bowlers								
BD	199	85	23	46	9.2		223	3.0
SG	197	46	14	31	6.3		236	2.3
BC	200	48	16	34	8.5		173	2.7
BC	107	38	23	39	7.9		103	2.5
BD	160	56	24	56	9.0		140	2.9
IC	155	28	16	31	7.2		82	2.7
MH	160	58	18	71	8.5		162	2.3
BC	185	72	19	38	8.6		160	2.9
TD	179	44	16	71	6.6		189	2.7
TD	194	45	17	38	6.8		195	3.1
JH	194	60	20	47	7.5		133	3.3
MH	194	32	15	40	7.3		144	2.6
TD	194	26	17	57	8.4		103	2.7
MH	210	31	16	48	6.5		143	2.7
BC	173	50	13	26	7.9		166	2.3
PG	173	54	18	35	7.9		132	2.8
BC	210	104	14	49	9.0		327	2.7
MH	210	67	17	50	8.8		163	2.4
BC	187	57	16	47	8.9		220	2.5
MH	187	57	18	33	8.4		115	2.6
BC	189	47	19	59	8.7		184	2.7
BC	204	69	16	53	8.2		214	2.5
TK	204	80	18	61	8.9		165	2.8
BC	192	53	17	47	8.6		179	2.6
Mean	**186**	**54**	**18**	**46**	**8.1**		**169**	**2.7**
SD	*23*	*19*	*3*	*12*	*0.9*		*52*	*0.3*

One Day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fielders											
AF	195	6197	2272	673	959	626	10727			11201	494
LR	212	5543	1272	431	521	331	8098			7607	282
MH	198	8270	2645	463	469	187	12034			11620	287
PH	159	5999	2737	431	403	182	9752			9287	240
DW	198	8224	2301	411	366	324	11626			11552	238
PH	194	6721	2049	240	295	133	9438			11476	166
CP	63	1859	416	92	76	16	2459			3768	45
DW	141	4323	565	63	70	32	5053			8428	42
LP	108	3543	713	53	82	29	4420			6418	36
LR	163	5819	1316	174	208	216	7733			9634	123
MH	152	4212	1619	229	96	48	6204			9014	98
PH	66	2161	672	131	81	11	3056			3914	52
LR	191	4587	1398	304	337	62	6688			11268	189
MH	202	9931	1572	224	230	166	12123			11937	143
DW	148	4764	1936	378	376	173	7627			8627	111
MH	84	2801	815	163	154	81	4014			4935	98
PF	150	4582	1808	447	581	463	7881	117	164	8663	337
SO	179	6160	2972	527	563	432	10654			10383	348
UK	180	6739	2722	509	539	313	10822			10483	314
MH	194	8870	2436	483	559	456	12804			11291	348
MH	194	7379	1636	374	319	288	9996	113	169	11417	218
PF	194	6471	2518	565	670	422	10646	111	158	11255	382
UK	194	7297	3309	775	659	423	12463			11190	444
GM	194	5305	2271	404	415	397	8792			11295	278
LD	194	5786	1659	244	262	380	8331			11306	191
PF	194	6473	2441	436	498	313	10161	98	169	11329	293
LD	210	7795	2846	437	531	268	11877			12316	282
MW	210	7719	2808	689	888	817	12921			12068	528
PF	210	8230	2119	331	355	356	11392	104	169	12322	233

Continued from previous table (One Day Fielders)

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fielders											
UK	210	7515	3520	571	683	418	12707			12202	391
LD	175	4254	1139	166	127	62	5748			10319	93
MH	173	6377	1742	230	143	63	8555			10236	106
SO	173	6731	1593	274	300	181	9079			10196	174
UK	173	6137	2104	302	230	211	8984			10056	171
GM	210	6443	2516	629	403	277	10268			12283	309
LD	26	658	212	26	20	5	921			1546	12
MH	210	9472	1946	369	194	166	12147			12424	167
PF	210	7781	2222	471	525	193	11192			12216	284
GM	187	5141	1205	265	229	64	6904			10406	132
MH	187	8621	1948	291	407	238	11505			10994	213
PF	127	3871	1502	312	241	91	6017			7457	158
UK	187	7309	2318	385	392	408	10812			10958	255
LD	189	6604	2334	338	293	261	9830			11139	181
MH	189	7891	1576	288	327	295	10377			11129	204
PF	189	5581	1318	386	488	218	7991			10378	253
AK	73	2362	751	164	202	212	3691			4260	118
CF	204	8305	2992	493	645	400	12835			11889	340
MH	204	5816	852	87	111	67	6933			12007	57
CF	192	8508	2762	561	652	244	12727			11165	329
MH	192	9671	1730	360	381	222	12364			11269	220
TD	192	7434	1343	315	339	241	9672			11318	194
UK	192	7507	2348	336	393	275	10859			11252	225
Mean	**174**	**6226**	**1881**	**352**	**371**	**245**	**9075**	**109**	**166**	**10060**	**220**
SD	*43*	*2070*	*775*	*170*	*211*	*165*	*3016*	*8*	*5*	*2503*	*118*

One Day

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fielders								
AF	195	40	15	53	8.9		182	3
LR	212	23	14	26	8.1		111	3
MH	198	18	11	28	5.7		130	2
PH	159	13	13	31	8.6		100	2
DW	198	22	13	32	8.0		96	2
PH	194	11	12	29	6.4		84	2
CP	63	1	11	11	5.6		20	2
DW	141	3	9	16	5.6		17	2
LP	108	1	21	21	6.0		13	3
LR	163	10	21	53	9.0		41	3
MH	152	2	22	26	6.2		40	2
PH	66	1	7	7	5.5		17	3
LR	191	6	10	23	5.6		89	2.1
MH	202	11	15	30	7.6		59	2.4
DW	148	12	14	22	5.6		71	1.6
MH	84	6	14	26	6.5		36	2.7
PF	150	26	18	54	8.0		113	3.0
SO	179	22	20	39	7.2		112	3.1
UK	180	17	18	32	6.9		110	2.9
MH	194	23	20	38	7.3		113	3.1
MH	194	16	18	72	8.6		73	3.0
PF	194	27	16	30	6.6		142	2.7
UK	194	26	16	37	6.9		153	2.9
GM	194	22	18	44	8.0		87	3.2
LD	194	21	18	44	7.3		58	3.3
PF	194	21	15	28	6.5		102	2.9
LD	210	18	15	23	5.9		91	3.1
MW	210	40	20	56	7.8		164	3.2
PF	210	21	17	37	6.7		86	2.7
UK	210	24	17	47	7.7		138	2.8

Continued from previous table (One Day Fielders)

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fielders								
LD	175	7	9	15	8.9		41	2.3
MH	173	6	9	13	6.2		53	2.0
SO	173	14	13	41	7.6		76	2.3
UK	173	13	16	37	7.5		68	2.5
GM	210	20	13	28	7.4		109	2.8
LD	26	1	5	5	5.2		4	3.0
MH	210	10	15	33	8.3		68	2.5
PF	210	16	12	32	8.9		117	2.4
GM	187	5	12	20	7.0		45	2.9
MH	187	20	12	25	7.1		89	2.4
PF	127	9	10	17	8.1		65	2.4
UK	187	25	16	40	8.5		99	2.6
LD	189	16	14	44	8.8		76	2.4
MH	189	20	15	51	8.2		79	2.6
PF	189	17	12	23	6.6		90	2.8
AK	73	10	19	49	8.5		32	3.7
CF	204	25	16	54	8.3		140	2.4
MH	204	4	15	21	6.7		26	2.2
CF	192	16	15	47	8.1		113	2.9
MH	192	14	16	61	7.3		78	2.8
TD	192	11	17	48	7.7		71	2.7
UK	192	20	14	35	8.4		82	2.7
Mean	**174**	**15**	**15**	**34**	**7.3**		**82**	**2.7**
SD	*43*	*9*	*4*	*14*	*1.1*		*40*	*0.4*

One Day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Spin bowlers											
AH	188	7762	2606	589	474	126	11557			10967	317
AH	200	7841	1816	329	270	73	10329			11744	176
AH	176	6437	1493	344	320	190	8784			10343	213
AH	120	4247	1003	160	195	58	5663			7043	111
AH	205	8570	1576	265	302	212	10925			12125	180
JH	194	7305	2821	334	316	187	10963			11435	202
UK	194	6482	1974	286	232	160	9134			11474	162
DW	210	6301	2215	615	924	493	10548			12070	462
Mean	**186**	**6868**	**1938**	**365**	**379**	**187**	**9738**			**10900**	**228**
SD	*29*	*1329*	*600*	*157*	*235*	*135*	*1894*			*1664*	*111*
Wicketkeepers											
MW	206	7762	2577	373	336	105	11153			12153	218
MW	172	5354	1429	323	292	64	7462			10150	168
GM	194	6068	1797	362	365	236	8828			11408	230
GM	210	5847	1939	471	492	145	8894			12330	269
MW	189	5793	1390	271	218	42	7714			11176	124
MW	204	6676	1856	341	211	77	9161			12083	148
Mean	**196**	**6250**	**1831**	**357**	**319**	**112**	**8869**			**11550**	**193**
SD	*14*	*857*	*430*	*66*	*105*	*71*	*1313*			*822*	*55*

One Day

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Spin bowlers								
AH	188	12	12	43	5.7		141	2.2
AH	200	10	8	17	5.7		99	1.8
AH	176	11	19	39	6.7		97	2.2
AH	120	6	11	22	5.4		57	1.9
AH	205	19	11	27	6.7		72	2.5
JH	194	10	19	32	7.6		63	3.2
UK	194	11	15	28	6.6		47	3.4
DW	210	21	23	56	6.0		131	3.5
Mean	**186**	**13**	**15**	**33**	**6.3**		**88**	**2.6**
SD	*29*	*5*	*5*	*13*	*0.7*		*35*	*0.7*
Wicketkeepers								
MW	206	9	13	30	7.4		102	2.1
MW	172	2	32	18	5.2		54	3.1
GM	194	16	15	39	8.1		70	3.3
GM	210	9	16	16	4.9		97	2.8
MW	189	5	7	10	5.7		61	2.0
MW	204	6	11	16	7.6		74	2.0
Mean	**196**	**8**	**16**	**22**	**6.5**		**76**	**2.6**
SD	*14*	*5*	*9*	*11*	*1.4*		*19*	*0.6*

Multi-day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Batsmen											
BC	26.5	1143	177	36	76	36	1468			1551	32
DO	51	1252	129	70	94	31	1576			3013	45
GM	35	896	84	37	51	59	1127			2065	33
MH	59	1733	153	63	79	83	2111			3491	46
PF	275	7428	968	250	492	541	9679			16087	270
UK	120	2760	315	121	204	257	3657			7071	124
LD	117	3341	394	117	163	151	4166			6921	94
MH	76.3	1789	352	125	188	109	2563			4392	94
UK	117	1863	201	75	140	113	2392			4541	75
Mean	**97**	**2467**	**308**	**99**	**165**	**153**	**3193**			**5459**	**90**
SD	*76*	*2016*	*269*	*66*	*134*	*161*	*2629*			*4420*	*74*

Raw data		Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
Batsmen							
BC	26.5	3	11	13	6.6	15	2.1
DO	51	3	12	15	7.1	22	2.0
GM	35	5	13	22	6.3	14	2.4
MH	59	8	10	17	8.6	24	1.9
PF	275	50	32	38	8.3	125	2.2
UK	120	25	10	28	7.2	61	2.0
LD	117	12	11	24	8.0	44	2.1
MH	76.3	13	8	14	6.6	50	1.9
UK	117	12	10	16	6.4	41	1.8
Mean	**97**	**15**	**13**	**21**	**7.2**	**44**	**2.1**
SD	*76*	*15*	*17*	*8*	*2.9*	*34*	*0.2*

Multi-day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fast bowlers											
BC	120	5336	1457	381	468	579	8221			6894	301
JS	120	5444	1921	483	608	579	9035			6827	367
MH	120	4709	856	168	232	124	6089			7080	115
BC	52	2073	490	57	29	46	2695			3086	31
JS	120	4943	1287	314	361	403	7308			6960	234
BC	58	2759	404	164	249	378	3954			3312	160
JS	57	1928	373	79	68	47	2495			3375	42
BC	46	2180	476	235	349	384	3624			2551	207
JS	50	2026	587	248	276	171	3308			2837	160
JS	118	4638	1327	499	672	501	7637			6699	377
Mean	86	3604	918	263	331	321	5437			4962	199
SD	*35*	*1522*	*543*	*155*	*209*	*209*	*2487*			*2049*	*122*

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fast bowlers								
BC	120	38	14	26	8.2		125	2.4
JS	120	40	15	34	8.0		140	2.6
MH	120	11	11	29	6.8		48	2.4
BC	52	3	14	32	6.3		13	2.4
JS	120	30	13	31	9.1		99	2.4
BC	58	28	13	20	6.7		64	2.5
JS	57	3	13	25	7.9		20	2.1
BC	46	30	13	21	6.4		83	2.5
JS	50	12	14	30	7.5		59	2.7
JS	118	35	14	31	7.5		150	2.5
Mean	**86**	**23**	**13**	**28**	**7.4**		**80**	**2.4**
SD	*35*	*14*	*1*	*5*	*0.9*		*48*	*0.2*

Multi-day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Fielders											
GM	120	3360	1128	169	150	116	4923			7102	91
LD	120	3767	479	76	87	52	4461			6989	49
MH	120	3192	748	183	164	127	4414			7089	105
PF	120	2519	975	150	119	78	3841			7112	83
GM	120	3968	1146	194	174	193	5675			7067	118
LD	120	2898	525	80	63	22	3588			7155	40
PF	120	3088	884	225	162	164	4523			6939	126
GM	57	1718	455	122	115	99	2509			3345	71
LD	56	1512	343	32	35	28	1950			3336	21
MH	55	1889	344	41	66	101	2441			3256	42
PF	57	1649	522	92	240	92	2595			3319	99
BC	117	4899	1341	251	190	34	6715			6892	115
GM	46	1135	221	24	12	25	1417			2746	13
LD	40	989	250	20	29	9	1297			2382	15
MH	48	1414	232	55	46	21	1768			2849	28
PF	44	951	365	68	22	18	1424			2610	28
GM	113	3473	1266	263	325	147	5474			6615	159
LD	120	3661	1637	381	210	41	5930			6835	156
MH	120	4823	1219	228	150	103	6523			7021	113
PF	117	4331	1263	230	236	128	6188			6748	134
Mean	**92**	**2762**	**767**	**144**	**130**	**80**	**3883**			**5370**	**80**
SD	*35*	*1284*	*446*	*90*	*86*	*55*	*1851*			*2019*	*48*

Multi-day

Raw data			Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fielders								
GM	120	5	21	39	8.7		27	3.4
LD	120	4	13	20	6.9		23	2.1
MH	120	5	20	36	8.0		35	3.0
PF	120	4	17	38	7.1		34	2.4
GM	120	9	19	36	7.8		51	2.3
LD	120	2	10	13	6.7		16	2.5
PF	120	5	33	58	8.1		37	3.4
GM	57	4	24	39	8.2		22	3.2
LD	56	1	28	28	7.4		8	2.6
MH	55	9	11	26	7.5		19	2.2
PF	57	4	23	33	5.6		28	3.5
BC	117	2	8	8	5.8		46	2.5
GM	46	2	11	12	6.9		5	2.6
LD	40	1	9	9	5.5		7	2.1
MH	48	2	10	10	6.8		11	2.5
PF	44	2	9	13	5.3		14	2.0
GM	113	8	17	41	8.1		60	2.7
LD	120	3	9	11	6.5		61	2.6
MH	120	8	13	23	7.6		44	2.6
PF	117	7	17	36	7.6		49	2.7
Mean	**92**	**4**	**16**	**26**	**7.1**		**30**	**2.7**
SD	*35*	*3*	*7*	*14*	*1.0*		*18*	*0.4*

Multi-day

Raw data		Distance (m) covered						Heart rate (bpm)		Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	Walking & Jogging	Running, Striding, Sprinting
Wicketkeepers											
DO	120	3821	1017	117	48	30	5033			7147	46
DO	120	4418	888	72	56	12	5446			6960	37
DO	47	1752	644	57	55	53	2561			2781	37
DO	117	4255	621	71	34	5	4986			6987	28
Mean	**101**	**3562**	**793**	**79**	**48**	**25**	**4507**			**5969**	**37**
SD	*36*	*1232*	*192*	*26*	*10*	*21*	*1313*			*2127*	*7*

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
Wicketkeepers							
DO	120	1	24	24	7.2	20	2.3
DO	120	2	7	7	6.0	15	2.5
DO	47	6	9	13	8.0	17	2.2
DO	117	1	5	5	5.1	18	1.6
Mean	**101**	**3**	**11**	**12**	**6.6**	**18**	**2.1**
SD	*36*	*2*	*9*	*9*	*1.3*	*2*	*0.4*

Study 7: State v International

Raw data	Distance (m) covered							Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fast bowlers – 1-Day									
BD	218	9570	2798	631	831	980	14810	12529	541
BG	218	7686	1679	315	447	1187	11314	12083	405
NB	185	7597	2091	424	688	1390	12190	10453	524
BD	195	9228	2294	613	749	825	13709	11203	460
BE	204	10396	2814	593	924	1213	15940	11659	573
NB	197	8522	1507	395	571	943	11938	11205	413
SM	204	8266	2295	495	766	1749	13571	11650	576
SW	156	7470	2335	543	654	770	11772	8925	414
Mean	**197**	**8592**	**2227**	**501**	**704**	**1132**	**13156**	**11213**	**488**
SD	20	1055	467	114	150	325	1634	1114	74

Raw data	Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
State							
Fast bowlers – 1-Day							
BD	218	66	14	47	8.1	188	2.9
BG	218	79	15	34	7.5	145	2.8
NB	185	75	19	40	7.8	181	2.9
BD	195	50	15	35	8.1	163	2.8
BE	204	75	16	62	8.3	226	2.5
NB	197	61	15	28	7.7	164	2.5
SM	204	74	23	62	8.4	187	3.1
SW	156	49	15	31	9.0	142	2.9
Mean	**197**	**66**	**17**	**42**	**8.1**	**175**	**2.8**
SD	20	12	3	13	0.5	27	0.2

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fast bowlers – 1st Class									
BD	116	5836	1434	247	294	324	8135	6743	197
BG	125	5714	1480	380	528	635	8737	7134	342
LB	127	4415	952	213	318	548	6446	7356	228
BD	120	5857	1820	329	389	650	9045	6927	290
BG	101	4918	1090	185	307	729	7229	5825	249
LB	124	3557	770	157	185	263	4932	7236	130
BD	153	6662	1348	268	377	375	9030	8866	252
BG	152	5706	1025	216	313	660	7920	8805	261
LB	150	4926	1076	232	346	1012	7592	8597	322
BD	124	4962	1131	208	318	306	6925	7260	191
BG	124	4834	1530	213	324	532	7433	7220	229
NB	98	5867	1109	232	349	678	8235	5598	266
NB	151	7701	1777	289	438	756	10961	8699	349
NB	154	7371	1853	401	658	962	11245	8089	544
NB	83	4193	1205	241	348	492	6479	4715	241
NB	148	7869	1424	372	549	1077	11291	8459	423
RH	124	9880	2282	366	458	937	13923	7026	376
RH	119	7993	1701	304	437	864	11299	6759	363
RH	105	5260	932	173	202	398	6965	6115	164
JH	125	8202	1775	375	512	862	11726	7185	314
JH	123	8249	1522	249	353	998	11371	7087	293
JH	107	4853	807	96	177	492	6425	5655	141
RH	81	4947	1028	226	322	493	7016	4647	207
RH	140	6825	1079	186	293	498	8881	8233	214
BD	120	5167	731	269	502	524	7193	6934	257

Continued from previous table

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fast bowlers – 1st Class									
SM	120	5882	1342	259	339	1054	8876	6783	305
TD	120	5973	910	177	271	147	7478	6930	137
TK	120	6148	947	167	360	803	8425	6945	250
BD	130	5178	990	208	480	656	7512	7174	262
SM	130	6588	1249	253	480	1334	9904	7322	368
TK	130	6330	657	164	356	1085	8592	7508	286
DT	120	5947	2003	292	330	415	8987	8165	229
NB	120	6214	889	280	445	659	8487	6923	272
NB	118	6139	1467	296	424	797	9123	6740	316
BD	131	5838	1254	246	452	887	8677	7477	315
SM	141	6421	1720	206	382	1128	9857	8145	310
TK	141	6350	891	172	379	829	8621	8180	274
BD	125	5347	812	218	386	846	7609	7202	294
SM	125	5492	738	152	209	640	7231	7307	188
TK	125	6764	1077	257	393	1067	9558	7148	338
BD	120	4524	646	162	273	589	6194	6994	201
SM	120	5362	812	195	309	1070	7748	6911	284
TK	120	5895	927	144	239	428	7633	7032	163
BD	82	3144	685	157	346	660	4992	4690	225
NB	55	2939	620	184	377	510	4630	3074	224
SM	82	3172	516	79	151	541	4459	4714	192
TK	82	3136	507	117	321	310	4391	4756	160
BE	120	5816	1087	304	324	393	7924	6948	208
BD	120	5934	1176	308	575	707	8700	6809	295
SM	120	5769	692	174	272	1340	8247	6867	328

Continued from previous table

Raw data		Distance (m) covered							Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance		Walking & Jogging	Running, Striding, Sprinting
State										
Fast bowlers – 1st Class										
TD	120	6117	883	189	229	156	7574		7051	128
BE	120	6059	1652	336	471	576	9094		6893	302
BD	120	4688	821	202	334	521	6566		7004	191
SM	120	5276	613	120	132	735	6876		7017	177
TD	120	6337	1628	263	395	392	9015		6956	232
BE	67	2726	808	123	223	351	4231		3853	148
BH	74	3388	967	244	368	268	5235		4234	202
BD	67	1966	304	57	158	170	2655		3907	90
SM	67	2840	590	105	184	680	4399		3831	185
BH	120	5898	1293	277	410	664	8542		6927	269
BH	120	5987	985	225	318	581	8096		6966	229
BE	100	4841	1204	237	307	674	7263		5726	264
BH	29	1160	296	114	159	196	1925		1606	133
BD	100	4653	975	196	386	428	6638		5777	219
SM	100	3181	421	59	119	719	4499		5826	159
BE	120	5675	963	159	350	385	7532		7018	177
BD	120	5702	722	189	334	927	7874		6904	282
SM	120	5826	756	147	368	649	7746		6985	211
TD	120	5070	928	150	316	303	6767		6881	174
BE	120	5773	1209	283	383	555	8203		6951	241
SM	120	5505	1560	297	310	476	8148		6367	220
TD	120	5090	1582	290	396	247	7605		6970	209
BE	140	5392	1172	348	422	692	8026		8059	308
BD	140	6010	930	319	471	1180	8910		7965	380
SM	140	6120	1319	210	289	748	8686		8117	264

Continued from previous table

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fast bowlers – 1st Class									
NB	82	3466	663	61	58	91	4339	4857	43
NB	127	5962	1566	263	437	1260	9488	7122	398
NB	59	2820	853	225	378	303	4579	3300	195
NB	102	4770	813	166	445	454	6648	5882	232
NB	82	3466	663	61	58	91	4339	4857	43
Mean	115	5404	1094	222	349	640	7710	6616	249
SD	24	1471	410	79	113	291	2075	1391	82

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fast bowlers – 1st Class								
BD	116	21	14	35	9.3		68	2.9
BG	125	39	16	46	7.9		119	2.9
LB	127	32	17	34	8.0		76	3.0
BD	120	40	16	54	8.5		97	3.0
BG	101	53	14	53	7.2		89	2.8
LB	124	16	16	37	8.9		49	2.7
BD	153	27	16	40	7.6		73	3.5
BG	152	42	17	54	7.9		89	2.9
LB	150	59	18	42	9.3		104	3.1
BD	124	20	16	67	9.1		58	3.3
BG	124	39	14	26	8.2		87	2.6
NB	98	39	17	50	7.9		99	2.7
NB	151	52	16	26	7.5		127	2.7
NB	154	77	16	50	8.3		186	2.9
NB	83	32	15	40	8.4		94	2.6
NB	148	66	16	62	9.4		155	2.7
RH	124	72	15	66	9.3		343	1.1
RH	119	53	18	47	9.2		116	3.1
RH	105	28	15	30	9.6		57	2.9
JH	125	41	18	55	8.3		107	2.9
JH	123	44	22	58	8.7		91	3.2
JH	107	21	23	63	8.2		48	2.9
RH	81	34	12	22	7.3		79	2.6
RH	140	31	16	40	8.6		75	2.9
BD	120	34	14	39	7.3		101	2.5

Continued from previous table

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fast bowlers – 1st Class								
SM	120	53	20	45	8.0		114	2.7
TD	120	8	18	36	8.3		54	2.5
TK	120	37	21	48	8.3		90	2.8
BD	130	46	13	30	7.1		112	2.3
SM	130	66	19	48	8.5		131	2.8
TK	130	47	23	55	9.0		98	2.9
DT	120	31	14	47	8.7		101	2.3
NB	120	43	15	43	8.8		113	2.4
NB	118	49	17	37	8.8		126	2.5
BD	131	52	17	44	8.9		117	2.7
SM	141	59	18	40	8.0		114	2.7
TK	141	45	19	44	8.9		91	3.0
BD	125	45	19	34	7.7		107	2.7
SM	125	33	20	34	7.4		77	2.4
TK	125	52	21	66	8.7		109	3.1
BD	120	32	18	42	7.0		77	2.6
SM	120	46	23	48	9.1		90	3.2
TK	120	22	20	65	9.1		62	2.6
BD	82	40	16	27	8.7		89	2.5
NB	55	29	18	34	7.9		78	2.9
SM	82	34	22	40	8.3		62	3.1
TK	82	17	18	36	7.8		50	3.2
BE	120	24	15	36	8.2		90	2.3
BD	120	40	16	88	7.9		109	2.7
SM	120	53	26	62	8.0		96	3.4

Continued from previous table

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fast bowlers – 1st Class								
TD	120	13	11	41	7.8		58	2.2
BE	120	37	16	43	7.8		122	2.5
BD	120	28	16	36	7.8		81	2.4
SM	120	29	25	41	7.6		51	3.5
TD	120	36	11	39	8.0		111	2.1
BE	67	18	20	46	9.0		50	3.0
BH	74	25	12	28	7.9		82	2.5
BD	67	10	20	58	8.4		35	2.6
SM	67	33	22	34	9.1		57	3.2
BH	120	41	16	48	8.9		104	2.6
BH	120	36	16	51	9.7		96	2.4
BE	100	41	17	46	9.4		97	2.7
BH	29	22	13	27	7.4		60	2.2
BD	100	26	16	56	9.7		87	2.5
SM	100	27	27	61	9.5		44	3.6
BE	120	22	16	33	8.1		71	2.5
BD	120	49	19	34	8.5		107	2.6
SM	120	36	18	47	8.1		81	2.6
TD	120	21	14	30	8.5		66	2.6
BE	120	31	16	41	9.4		87	2.8
SM	120	28	16	48	7.9		85	2.6
TD	120	14	16	54	8.7		80	2.6
BE	140	38	18	49	8.3		105	2.9
BD	140	50	24	59	8.5		114	3.3
SM	140	48	17	32	9.7		96	2.8

Continued from previous table

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fast bowlers – 1st Class								
NB	82	52	17	56	9.3		128	2.9
NB	127	5	14	34	7.7		17	2.5
NB	59	60	22	60	8.8		134	3.0
NB	102	26	11	26	7.4		94	2.1
NB	82	49	9	23	6.9		166	1.4
Mean	**115**	**37**	**17**	**44**	**8.4**		**94**	**2.7**
SD	24	15	3	12	0.7		40	0.4

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fielders – 1-Day									
EC	184	7025	2628	607	737	586	11583	10626	424
GB	218	8464	2462	399	360	255	11940	12470	243
MD	218	7625	2947	650	731	337	12290	12712	405
PF	180	6329	2717	457	567	412	10482	10350	353
CP	155	8341	2787	437	481	518	12564	8967	355
CF	137	5346	1926	371	376	472	8491	7913	274
DH	143	7108	2137	394	415	426	10480	8298	280
NA	139	4231	1055	251	238	67	5842	8195	140
AV	204	8097	1983	419	676	507	11682	11882	349
MN	204	10032	2295	450	548	94	13419	11924	260
PF	197	6024	2206	569	711	690	10200	11363	448
SM	193	8054	3444	698	646	264	13106	11190	376
DW	200	6897	1907	512	615	484	10415	11635	348
EC	200	8476	3265	602	578	714	13635	10868	423
AV	121	4613	1422	318	228	102	6683	7100	154
BR	173	7326	2187	499	427	402	10841	9997	316
DW	180	6338	1978	646	552	447	9961	10404	386
LD	52	2206	625	86	85	182	3184	3046	73
Mean	**172**	**6807**	**2221**	**465**	**498**	**387**	**10378**	**9941**	**312**
SD	42	1854	718	155	188	194	2779	2381	106

Raw data	Sprint data						High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fielders – 1-Day								
EC	184	32	17	49	8.2		140	3.0
GB	218	16	13	25	8.8		87	2.8
MD	218	21	13	37	6.5		128	3.2
PF	180	30	12	24	7.9		119	3.0
CP	155	39	15	42	8.2		128	2.8
CF	137	22	20	56	8.8		84	3.3
DH	143	24	17	40	9.0		94	3.0
NA	139	5	10	19	5.8		47	3.0
AV	204	28	17	58	8.3		127	2.7
MN	204	9	8	11	6.2		102	2.5
PF	197	39	17	59	9.3		171	2.6
SM	193	17	14	41	8.8		136	2.8
DW	200	29	15	52	9.5		125	2.8
EC	200	47	15	56	9.5		181	2.3
AV	121	11	10	15	8.8		66	2.3
BR	173	28	14	61	9.4		137	2.3
DW	180	23	19	62	9.3		131	2.9
LD	52	9	20	41	8.6		28	2.6
Mean	**172**	**24**	**15**	**42**	**8.4**		**113**	**2.8**
SD	42	11	3	17	1.1		40	0.3

Raw data Player	Duration (min)	Distance (m) covered Walking	Jogging	Running	Striding	Sprinting	Total Distance		Time (s) spent Walking & Jogging	Running, Striding, Sprinting
State										
Fielders– 1st Class										
GB	125	4067	693	73	85	60	4978		7423	55
MD	127	4938	1631	366	501	285	7721		7191	257
MD	125	5266	1322	206	271	408	7473		7314	178
GB	152	4744	783	197	193	136	6053		8951	138
MD	153	5396	1650	244	262	311	7863		8941	191
GB	125	4131	951	116	117	179	5494		7403	86
MD	125	4165	1030	192	264	205	5856		7351	145
EC	151	4208	662	139	185	135	5329		8905	119
PF	154	5501	1501	279	344	291	7916		8717	226
EC	61	1799	371	75	52	40	2337		3595	44
NB	62	2915	478	55	66	96	3610		3682	47
PF	60	3025	805	124	143	239	4336		3481	101
EC	143	4882	1289	397	339	367	7274		8295	246
PF	154	6715	2240	334	422	317	10028		8413	242
EC	81	2989	824	214	215	238	4480		4711	147
PF	81	3481	753	58	62	128	4482		4838	48
EC	157	5812	928	161	229	192	7322		9285	126
PF	158	7474	1461	207	253	170	9565		9286	154
AD	125	6428	2085	355	325	514	9707		7256	245
CF	124	5772	1408	227	234	246	7887		7278	186
MK	41	2576	729	115	108	38	3566		2372	68
SD	126	4089	355	56	71	27	4598		7498	39
AD	120	6134	2182	398	384	328	9426		6933	243
CF	119	5187	1625	292	250	128	7482		7006	158
SD	37	1363	241	23	6	3	1636		2208	10

Continued from previous table

Raw data Player	Duration (min)	Distance (m) covered Walking	Jogging	Running	Striding	Sprinting	Total Distance	Time (s) spent Walking & Jogging	Running, Striding, Sprinting
State									
Fielders– 1st Class									
AD	105	4623	1422	272	323	270	6910	6083	200
CF	106	2592	893	208	184	79	3956	6220	137
CP	29	628	167	34	47	36	912	1702	28
JH	32	1800	553	111	127	61	2652	1849	70
SW	40	741	213	86	70	12	1122	2361	39
CP	124	2847	770	190	161	145	4113	7295	128
SW	124	3781	686	97	97	28	4689	7375	61
CP	124	3065	629	191	176	85	4146	7295	113
SW	107	3498	889	146	98	58	4689	6334	80
CP	105	2730	689	266	209	152	4046	6158	148
SW	107	3523	656	128	117	65	4489	6340	69
AD	71	3580	1453	256	383	259	5931	4101	183
CF	72	1868	290	63	107	176	2504	4221	84
DH	69	2746	893	249	233	142	4263	3973	155
AD	129	5800	1904	280	206	252	8442	7576	161
CF	128	3344	877	183	199	42	4645	7601	104
DH	129	5851	1720	371	464	252	8658	7457	273
CP	88	2134	549	141	127	44	2995	5204	91
JH	82	3995	1126	194	207	403	5925	4361	172
LD	120	3422	534	121	115	38	4230	7115	70
AV	130	2912	1472	406	396	328	5514	7544	251
LD	130	4338	1171	216	206	127	6058	7671	124
TD	130	6423	1226	157	172	86	8064	7696	98
AV	141	3003	1007	325	382	251	4968	8240	214
DB	141	3960	887	245	370	224	5686	8259	196

Continued from previous table

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fielders– 1st Class									
TD	141	5445	961	286	285	137	7114	7864	170
AH	125	5337	1473	190	230	297	7527	7332	160
TD	125	4449	665	234	125	28	5501	7370	95
AH	120	3980	1396	279	246	262	6163	7024	171
TD	120	4507	914	240	223	204	6088	7051	144
AH	60	1959	563	92	98	61	2773	3529	69
AV	82	1472	772	196	267	139	2846	4684	143
TD	82	2576	449	138	231	86	3480	4795	122
AV	120	2007	953	292	415	200	3867	6991	204
LD	120	2787	434	78	70	32	3401	6941	43
AV	120	2344	868	299	483	374	4368	6950	245
LD	105	2657	1107	163	172	536	4635	6092	175
LD	67	1854	385	67	80	98	2484	3963	55
MD	74	2151	604	161	114	115	3145	4353	84
TD	62	2456	604	81	101	88	3330	3649	68
TB	74	1759	402	150	134	79	2524	4343	87
XD	74	2550	366	101	184	195	3396	4339	98
RL	120	4990	1168	185	167	121	6631	7090	105
XD	60	1833	251	44	79	82	2289	3553	42
RL	60	2501	387	52	85	114	3139	3545	52
LD	100	2598	517	144	127	33	3419	5878	72
TD	100	3867	723	123	156	152	5021	5900	96
LD	120	3551	602	96	201	131	4581	7104	91
LP	120	3900	1053	239	147	114	5453	7074	109
BD	120	4445	702	285	434	208	6074	6979	210

Continued from previous table

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
State									
Fielders– 1st Class									
LD	120	2424	389	71	106	69	3059	7023	56
LD	140	4259	786	114	179	156	5494	8228	100
TD	140	5037	735	145	166	235	6318	8269	126
DH	120	5758	1630	248	221	144	8001	7036	149
DH	120	5199	1856	263	291	267	7876	6250	192
MK	120	3028	504	69	34	2	3637	6754	27
DH	120	4967	957	221	352	211	6708	6972	181
MK	120	3239	247	35	43	24	3588	7066	22
GM	82	3032	431	49	72	26	3610	4885	32
GM	127	4938	1235	197	313	320	7003	7445	170
GM	60	2355	614	231	289	69	3558	3427	140
BR	88	3512	997	185	155	264	5113	5131	130
GM	102	4108	1014	233	328	420	6103	5909	206
UK	102	3921	1094	297	302	224	5838	5931	185
GM	120	3897	704	95	85	122	4903	7124	71
NB	124	5552	813	175	335	274	7149	7267	174
UK	120	5167	1179	128	189	196	6859	7078	114
NB	82	3710	525	111	123	92	4561	4876	72
UK	85	2616	1117	197	252	226	4408	4952	145
Mean	**107**	**3734**	**913**	**182**	**205**	**169**	**5203**	**6217**	**127**
SD	31	1434	468	94	114	117	2013	1823	65

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fielders– 1st Class								
GB	125	5	11	17	7.7		20	2.8
MD	127	15	15	34	8.9		80	3.2
MD	125	23	18	60	7.8		55	3.2
GB	152	8	15	35	7.4		46	3.0
MD	153	15	21	64	8.7		54	3.5
GB	125	6	25	61	8.4		24	3.6
MD	125	10	18	43	8.1		44	3.3
EC	151	10	13	36	9.3		46	2.6
PF	154	20	15	40	8.5		71	3.2
EC	61	3	10	13	6.1		12	3.7
NB	62	8	11	22	7.5		17	2.8
PF	60	8	26	49	8.7		25	4.0
EC	143	15	29	112	9.4		76	3.2
PF	154	43	7	27	9.4		256	0.9
EC	81	10	18	45	7.7		44	3.3
PF	81	5	23	24	8.7		9	5.3
EC	157	9	21	40	7.4		38	3.3
PF	158	9	16	55	9.0		40	3.9
AD	125	22	22	66	8.8		76	3.2
CF	124	16	15	50	8.3		68	2.7
MK	41	2	7	8	7.1		17	4.0
SD	126	2	13	15	6.6		14	2.8
AD	120	18	17	46	8.3		76	3.2
CF	119	8	12	18	7.0		52	3.0
SD	37	0	0	0	5.5		3	3.3

Continued from previous table

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fielders– 1st Class								
AD	105	11	22	56	8.3		60	3.3
CF	106	6	12	30	7.0		48	2.9
CP	29	3	12	16	6.4		11	2.5
JH	32	3	13	22	7.1		18	3.9
SW	40	0	0	0	5.0		13	3.0
CP	124	7	23	40	8.0		37	3.5
SW	124	2	11	14	5.5		21	2.9
CP	124	6	10	15	8.8		39	2.9
SW	107	3	17	20	8.0		25	3.2
CP	105	5	21	33	7.5		44	3.4
SW	107	2	21	25	6.2		25	2.8
AD	71	15	13	31	7.6		71	2.6
CF	72	11	17	32	9.3		28	3.0
DH	69	12	11	31	7.3		56	2.8
AD	129	10	25	55	8.7		47	3.4
CF	128	3	8	12	5.5		37	2.8
DH	129	17	12	61	9.6		84	3.3
CP	88	2	23	36	6.7		24	3.8
JH	82	12	32	80	9.4		54	3.2
LD	120	2	17	20	6.7		31	2.3
AV	130	18	18	37	7.2		83	3.0
LD	130	11	10	22	7.1		53	2.3
TD	130	9	9	18	7.4		43	2.3
AV	141	14	17	45	7.9		66	3.2
DB	141	18	13	42	7.6		67	2.9

Continued from previous table

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fielders– 1st Class								
TD	141	6	22	41	7.6		57	3.0
AH	125	15	18	53	8.1		57	2.8
TD	125	1	24	24	7.5		35	2.7
AH	120	14	19	47	8.2		60	2.9
TD	120	11	18	56	9.5		55	2.6
AH	60	5	13	24	6.6		27	2.6
AV	82	9	17	32	6.6		59	2.4
TD	82	5	16	30	6.1		39	3.1
AV	120	8	24	53	6.4		56	3.6
LD	120	2	18	22	6.1		19	2.3
AV	120	19	19	46	8.0		71	3.5
LD	105	21	26	56	9.2		56	3.1
LD	67	5	22	32	7.9		20	2.8
MD	74	4	27	44	9.1		35	2.4
TD	62	7	13	20	8.9		34	2.0
TB	74	4	18	23	6.4		34	2.6
XD	74	7	27	46	8.7		33	3.0
RL	120	6	19	38	7.7		46	2.3
XD	60	5	16	43	7.2		19	2.2
RL	60	5	25	38	8.0		20	2.6
LD	100	2	12	19	7.1		22	3.3
TD	100	6	24	55	8.6		42	2.3
LD	120	9	14	23	7.0		32	2.8
LP	120	6	18	42	11.8		38	2.9
BD	120	10	16	53	8.2		56	3.8

Continued from previous table

Raw data		Sprint data					High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
State								
Fielders– 1st Class								
LD	120	5	13	34	7.3		23	2.4
LD	140	8	19	31	8.1		36	2.8
TD	140	12	19	45	8.4		46	2.7
DH	120	12	12	46	7.7		66	2.3
DH	120	16	18	62	7.8		69	2.8
MK	120	0	0	0	4.8		11	2.5
DH	120	15	12	46	8.4		81	2.2
MK	120	2	13	19	6.2		9	2.4
GM	82	3	7	11	5.3		15	2.1
GM	127	12	25	56	8.2		58	2.9
GM	60	5	14	30	6.1		34	4.1
BR	88	16	19	62	8.2		48	2.7
GM	102	19	23	54	8.0		78	2.6
UK	102	12	18	52	8.9		66	2.8
GM	120	7	18	32	7.1		30	2.4
NB	124	29	9	18	6.9		111	1.6
UK	120	14	15	42	9.1		50	2.3
NB	82	6	16	35	6.9		40	1.8
UK	85	14	16	35	8.3		54	2.7
Mean	**107**	**9**	**17**	**37**	**7.7**		**46**	**2.9**
SD	31	7	6	18	1.2		31	0.6

Raw data		Distance (m) covered							Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance		Walking & Jogging	Running, Striding, Sprinting
International										
Fast bowlers – ODI										
SC	208	9562	1080	211	370	909	12132		12230	269
NB	227	11696	1597	461	639	1322	15715		13123	508
MJ	196	9278	1657	428	634	1319	13316		11261	482
NB	195	7104	1215	361	562	1258	10500		11255	474
MJ	224	8405	2217	575	1009	1229	13435		12835	592
NB	228	11583	1781	418	730	981	15493		13226	430
NB	215	16600	1723	444	796	1095	20658		12410	494
NB	226	9124	2622	574	753	1678	14751		12909	634
NB	213	11439	2327	661	888	1101	16416		12213	558
NB	147	8266	2670	539	723	998	13196		8328	468
NB	202	11648	2801	552	821	1181	17003		11583	561
NB	129	7333	2371	396	583	620	11303		7387	323
NB	126	6067	1970	491	575	634	9737		7196	359
SC	126	5860	1581	320	513	929	9203		7131	347
NB	162	7747	1539	367	475	486	10614		9216	279
SW	161	6128	1549	348	325	778	9128		9352	299
JH	137	6473	1233	263	427	808	9204		7665	291
MJ	72	3373	611	147	197	619	4947		4133	181
NB	137	6428	2075	402	620	740	10265		7843	368
SW	137	5621	1348	295	372	651	8287		7940	275
SC	137	7336	1548	305	418	858	10465		7897	314
Mean	**172**	**8432**	**1786**	**408**	**592**	**962**	**12179**		**9863**	**405**
SD	45	2938	567	130	203	300	3607		2623	126

Raw data	Sprint data						High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
International								
Fast bowlers – ODI								
SC	208	41	22	45	7.4		82	3.3
NB	227	73	19	43	7.9		180	2.8
MJ	196	76	17	48	7.6		177	2.7
NB	195	63	22	76	7.1		172	2.8
MJ	224	79	15	31	8.7		218	2.7
NB	228	57	17	32	8.7		155	2.8
NB	215	76	15	44	9.1		180	2.7
NB	226	82	21	63	8.9		209	3.0
NB	213	62	18	53	8.3		193	2.9
NB	147	58	18	89	8.6		170	2.8
NB	202	68	20	82	7.6		203	2.8
NB	129	42	14	30	9.3		132	2.4
NB	126	36	18	50	9.6		130	2.8
SC	126	53	17	27	7.3		135	2.6
NB	162	34	13	29	6.4		107	2.6
SW	161	35	22	50	8.7		105	2.8
JH	137	38	21	60	8.2		109	2.7
MJ	72	34	17	39	8.5		65	2.8
NB	137	46	16	60	8.5		142	2.6
SW	137	36	19	47	7.3		99	2.8
SC	137	46	18	38	8.0		114	2.8
Mean	**172**	**54**	**18**	**49**	**8.2**		**147**	**2.8**
SD	45	17	3	17	0.8		44	0.2

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
International									
Fielders – ODI									
AS	212	12361	767	157	127	59	13471	12663	82
AS	225	12000	1250	464	483	274	14471	13194	290
RP	228	13618	1871	370	267	69	16195	13247	182
AS	194	4870	990	257	278	119	6514	11478	157
AS	237	8676	1502	321	300	141	10940	14074	174
AS	222	7144	1785	292	368	144	9733	13144	190
MH	212	9163	3212	795	1094	852	15116	12084	635
MH	147	6118	2024	616	762	378	9898	8409	387
MH	207	9643	2851	609	746	594	14443	11983	461
MH	126	7026	2192	370	419	488	10495	7285	277
DH	126	3222	978	436	314	89	5039	7360	196
MH	126	4969	1607	477	553	170	7776	7275	280
DH	162	3320	941	525	757	110	5653	9393	320
MH	162	5756	1612	348	398	201	8315	9501	211
CW	137	4026	1301	242	174	51	5794	8094	121
MH	137	5583	1768	309	267	306	8233	8018	196
SM	137	5734	2572	377	298	258	9239	7994	221
Mean	**176**	**7249**	**1719**	**410**	**447**	**253**	**10078**	**10306**	**258**
SD	42	3184	691	160	257	218	3556	2496	136

Raw data	Sprint data						High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean sprint distance (m)	Max sprint distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
International								
Fielders – ODI								
AS	212	6	11	17	6.3		37	2.2
AS	225	15	17	40	8.0		91	3.2
RP	228	6	14	27	6.2		75	2.4
AS	194	9	12	29	7.8		59	2.7
AS	237	10	13	28	8.7		76	2.3
AS	222	9	13	30	8.0		81	2.3
MH	212	60	15	42	9.4		242	2.6
MH	147	23	15	35	8.6		136	2.8
MH	207	41	16	48	9.1		183	2.5
MH	126	20	24	62	9.3		100	2.8
DH	126	9	9	20	5.9		76	2.6
MH	126	15	10	28	7.3		115	2.4
DH	162	6	15	28	7.0		90	3.6
MH	162	14	13	31	7.4		76	2.8
CW	137	3	13	22	7.0		44	2.8
MH	137	15	19	52	9.5		83	2.4
SM	137	12	22	47	8.5		82	2.7
Mean	**176**	**16**	**15**	**34**	**7.9**		**97**	**2.6**
SD	42	14	4	12	1.2		50	0.3

Raw data		Distance (m) covered						Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Walking & Jogging	Running, Striding, Sprinting
International									
Fielders – Test									
AS	69	4463	1162	173	139	229	6166	4054	115
AS	134	5719	1495	227	219	298	7958	7857	154
MH	133	5078	1210	357	396	421	7462	7692	264
AS	123	6081	1209	189	231	255	7965	7217	150
MH	123	5480	1277	215	269	168	7409	7227	160
AS	142	6240	1682	307	401	632	9262	8276	264
MH	142	5160	1214	299	460	402	7535	8280	259
AS	108	4713	1097	211	255	327	6603	6298	167
MH	110	3639	1323	438	453	317	6170	6332	278
AS	82	4235	1191	237	293	162	6118	4737	155
MH	82	3333	864	184	212	83	4676	4796	119
AS	49	2404	508	98	146	145	3301	2850	82
MH	53	2244	687	123	149	167	3370	3080	92
AS	90	3791	1053	245	377	228	5694	5205	189
MH	92	2648	932	274	381	337	4572	5266	227
MH	152	3198	1260	434	613	276	5781	8805	310
MH	119	2868	1054	281	326	273	4802	6929	209
RL	129	5896	1400	195	293	289	8073	7540	172
MH	45	1255	390	105	83	29	1862	2661	63
MH	100	2922	1044	400	470	605	5441	5677	310
MH	127	3858	1371	364	490	515	6598	7341	286
MH	105	2776	833	121	126	192	4048	6159	128
MH	117	3959	1060	200	315	136	5670	6837	154
MH	120	3190	838	132	108	252	4520	7056	114
MH	59	1520	392	101	87	91	2191	3445	95
Mean	**104**	**3867**	**1062**	**236**	**292**	**273**	**5730**	**6065**	**181**
SD	31	1414	325	103	144	152	1890	1811	75

Raw data	Sprint data						High Intensity Effort data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
International								
Fielders – Test								
AS	69	7	30	59	9.4		29	4.0
AS	134	11	26	67	9.4		43	3.6
MH	133	19	22	47	8.4		93	2.8
AS	123	16	15	31	8.6		49	3.1
MH	123	9	16	42	7.8		58	2.8
AS	142	31	19	59	9.2		91	2.9
MH	142	16	23	44	9.4		80	3.2
AS	108	19	16	63	9.4		55	3.0
MH	110	21	13	41	8.6		91	3.1
AS	82	10	13	34	7.7		52	3.0
MH	82	6	11	19	8.3		43	2.8
AS	49	7	19	64	6.4		27	3.0
MH	53	7	21	48	7.8		32	2.9
AS	90	14	16	33	8.1		57	3.3
MH	92	21	16	37	7.6		89	2.6
MH	152	13	19	36	7.5		89	3.5
MH	119	12	23	47	7.6		63	3.3
RL	129	15	16	35	9.7		54	3.2
MH	45	2	17	27	9.3		24	2.6
MH	100	30	18	47	8.2		99	3.1
MH	127	24	18	51	8.9		96	3.0
MH	105	12	17	41	9.2		40	3.2
MH	117	10	12	21	7.7		54	2.9
MH	120	9	25	66	9.7		32	3.6
MH	59	10	10	16	7.8		28	3.4
Mean	**104**	**14**	**18**	**43**	**8.5**		**59**	**3.1**
SD	31	7	5	15	0.9		25	0.3

High Intensity Conditioning Sessions

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
GPS running												
JH	38	972	515	228	670	1931	4316	159	185	7.6	1750	531
PS	38	1135	478	281	872	1705	4471	163	194	6.3	1732	548
UK	38	1078	534	243	856	1493	4204	170	198	7.1	1760	521
VK	38	1272	570	284	843	1460	4429	163	194	10.6	1779	497
Mean	38	1114	524	259	810	1647	4355	164	193	8.1	1755	524
SD	*0*	*125*	*38*	*28*	*94*	*218*	*120*	*5*	*6*	*1.7*	*20*	*21*
Sprint session												
DW	46	731	579	447	1316	446	3519	168	199		970	483
SO	46	665	516	504	1286	505	3476	158	191	7.9	940	509
LD	33	695	625	648	1795	502	4265	164	197	8.9	1314	665
PF	33	1050	883	640	1526	635	4734	167	197	9.3	1344	632
JH	46	1237	667	869	2476	516	5765	158	186	11.8	1877	875
LD	46	1488	856	904	2187	662	6097	175	204	8.8	1862	831
MH	46	1341	837	926	2164	716	5984	159	189	8.4	1880	860
PF	46	1490	752	793	2247	795	6077				1892	858
TD	46	1141	769	1039	2101	646	5696	170	195	11	1867	883
DW	46	1433	847	1003	2206	516	6005				1904	847
JH	46	945	635	757	2631	584	5552	160	185	11.3	1867	885
MH	46	1240	988	823	2294	461	5806			8.6	1916	834
SO	46	1296	1171	936	1727	488	5618			10.3	2002	743
UK	46	1156	595	1045	2511	378	5685	171	204	8.8	1862	888
DW	52	1571	986	1199	2623	650	7029				2099	1021
JH	52	1084	737	886	3157	719	6583	160	185	12.2	2060	1061
MH	52	1371	1108	941	2838	558	6818			8.6	2107	1010
SO	52	1452	1329	1127	2119	577	6604			10.7	2212	902
TD	52							166	194	12		
UK	52	1276	666	1219	3080	434	6675	171	204	7.4	2043	1077
Mean	**46**	**1193**	**818**	**879**	**2225**	**568**	**5684**	**165**	**195**	**9.8**	**1790**	**835**
SD	*5*	*274*	*219*	*214*	*533*	*111*	*1021*	*6*	*7*	*1.6*	*369*	*166*

High Intensity Conditioning Sessions

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
GPS running							
JH	38	43	45	7.8		118	4.5
PS	38	47	36	7.4		123	4.5
UK	38	40	37	7.1		110	4.7
VK	38	44	33	7.1		130	3.8
Mean	**38**	**44**	**38**	**7.4**		**120**	**4.4**
SD	0	3	5	0.3		8	0.4
Sprint session							
DW	46	21	21	7.6		123	3.9
SO	46	28	18	7.8		146	3.5
LD	33	28	18	6.9		166	4.0
PF	33	36	18	7.7		186	3.4
JH	46	25	21	6.9		202	4.3
LD	46	38	17	6.7		211	3.9
MH	46	37	19	6.8		221	3.9
PF	46	41	19	8.0		222	3.9
TD	46	12	54	6.8		238	3.7
DW	46	28	18	6.6		218	3.9
JH	46	24	24	7.2		192	4.6
MH	46	24	19	8.5		203	4.1
SO	46	23	21	8.4		196	3.8
UK	46	27	14	6.0		210	4.2
DW	52	34	19	8.1		259	3.9
JH	52	33	22	7.3		228	4.7
MH	52	31	18	8.5		243	4.2
SO	52	27	21	8.4		233	3.9
TD	52						
UK	52	29	15	6.0		241	4.5
Mean	**46**	**29**	**21**	**7.4**		**207**	**4.0**
SD	5	7	8	0.8		34	0.3

High Intensity Conditioning Sessions

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Square run												
LD	24	477	921	286	296	1107	3087	167	198	10.9	1113	326
MH	24									11.7		
PF	24	535	856	364	319	1094	3168	156	195	10.0	1082	358
PS	24	466	990	178	262	1010	2906			9.8	1160	280
SO	24	581	893	284	314	1182	3254	157	189	8.3	1099	341
TM	24	443	897	217	230	927	2714	168	202	9.3	1163	275
TD	24	627	1020	234	336	1088	3305	154	188	9.8	1025	328
UK	24	489	1088	129	219	1032	2957	165	196	7.8	1180	260
VK	24	421	921	283	336	806	2767	160	197	10.0	1146	285
Mean	**24**	**505**	**948**	**247**	**289**	**1031**	**3020**	**161**	**195**	**9.7**	**1121**	**307**
SD	*0*	*71*	*78*	*73*	*46*	*118*	*219*	*6*	*5*	*1.2*	*52*	*36*
Tabata bike												
GS	45							141	163			
DW	45							141	177			
LD	45							151	189	10.6		
TD	45							145	183	12.3		
UK	45							153	184	10.1		
VK	45							149	189	10.8		
Mean	**45**							**147**	**181**	**11.0**		
SD	*0*							*5*	*10*	*0.9*		

High Intensity Conditioning Sessions

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Square run							
LD	24	25	44	7.5		71	4.6
MH	24						
PF	24	24	46	7.0		74	4.8
PS	24	27	37	7.2		67	4.2
SO	24	28	42	8.1		78	4.4
TM	24	24	39	7.3		65	4.2
TD	24	28	39	7.6		83	4.0
UK	24	24	43	6.7		58	4.5
VK	24	22	37	7.6		70	4.1
Mean	**24**	**25**	**41**	**7.4**		**71**	**4.3**
SD	0	2	3	0.4		8	0.3
Tabata bike							
GS	45						
DW	45						
LD	45						
TD	45						
UK	45						
VK	45						
Mean	**45**						
SD	0						

LOW Intensity Conditioning Sessions

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Fast bowler sprints												
GS	45.5	642	2270	962	1152	331	5357	166	187	5.1	1852	608
BC	48.0	976	3109	769	1204	1120	7178			5.0	2142	733
MH	48.0	1198	3034	593	980	1440	7245	164	190	3.4	2204	675
Mean	**47**	**939**	**2804**	**775**	**1112**	**964**	**6593**	**165**	**189**	**4.5**	**2066**	**672**
SD	*1*	*280*	*464*	*185*	*117*	*571*	*1071*	*1*	*2*	*1.0*	*188*	*73*
Field conditioning												
BH	29.5	863	2137	211	125	191	3527				1654	114
BG	27	707	2149	259	232	137	3484				1471	147
JH	27	896	2186	395	240	333	4050				1407	212
MH	27	723	2043	340	116	192	3414				1467	152
MJ	32.5	1400	1569	97	192	30	3288				1888	76
Mean	**29**	**918**	**2017**	**260**	**181**	**177**	**3553**				**1577**	**140**
SD	*2*	*282*	*256*	*116*	*58*	*110*	*292*				*197*	*50*
Sprint End.												
DW	26	1203	618	116	294	1493	3724				1213	347
LD	26	1177	507	129	357	1403	3573				1209	351
BC	44	2124	1033	212	516	2416	6301			6.2	2034	605
GM	44	2249	1032	196	686	2389	6552			6.2	2050	591
JH	44	2175	910	257	541	2479	6362			5.4	2043	596
MH	44	2145	992	319	559	2365	6380			6.9	2008	631
PF	44	2173	808	372	697	2518	6568			4.2	1958	681
SO	44	2167	919	281	603	2469	6439			3.7	2018	621
TD	44									6.9		
Mean	**40**	**1927**	**852**	**235**	**532**	**2192**	**5737**			**5.6**	**1817**	**553**
SD	*8*	*456*	*196*	*89*	*144*	*462*	*1293*			*1.3*	*375*	*129*

Low Intensity Conditioning Sessions

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fast bowler sprints							
GS	45.5	24	14	5.2		199	3.1
BC	48.0	85	13	6.1		278	2.6
MH	48.0	102	14	6.6		271	2.5
Mean	**47**	**70**	**14**	**6.0**		**249**	**2.7**
SD	1	41	1	0.7		44	0.3
Field conditioning							
BH	29.5	15	12	6.3		40	2.9
BG	27	15	9	6.3		52	2.8
JH	27	19	17	6.9		45	4.7
MH	27	13	15	6.4		31	4.9
MJ	32.5	3	8	5.5		33	2.3
Mean	**29**	**13**	**12**	**6.3**		**40**	**3.5**
SD	*2*	*6*	*4*	*0.5*		*9*	*1.2*
Sprint End.							
DW	26	21	71	7.1		51	6.8
LD	26	17	83	7.1		50	7.0
BC	44	38	64	8.1		99	6.1
GM	44	36	66	7.4		97	6.1
JH	44	26	95	7.0		76	7.8
MH	44	31	76	8.4		101	6.2
PF	44	37	68	7.4		132	5.2
SO	44	24	103	6.8		82	7.6
TD	44						
Mean	**40**	**29**	**78**	**7.4**		**86**	**6.6**
SD	*8*	***8***	***14***	***0.6***		***27***	***0.9***

LOW Intensity Conditioning Sessions

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Sprint technique												
BC	46	1665	679	107	112	164	2727	121	169	5.6	2674	85
DW	46	1268	375	65	114	204	2026				2678	78
GS	46	1643	520	94	144	101	2502	130	171	4.3	2690	68
IM	46	1603	488	89	109	154	2443				2685	73
JH	46	1483	482	84	158	188	2395	121	170	2.0	2625	91
LD	46	1516	485	116	150	99	2366	129	176	7.3	2677	82
MH	46	1601	497	95	128	164	2485			4.4	2655	86
MH	46	1499	469	77	133	266	2444	128	179	4.6	2625	91
PF	46	1598	420	91	167	312	2588	129	178	3.9	2649	110
SO	46	1252	324	67	117	215	1975	107	166	3.1	2669	83
TD	46	1644	418	94	162	271	2589	120	175	3.2	2649	111
UK	46	1387	433	85	112	150	2167	125	176	2.3	2681	79
Mean	**46**	**1513**	**466**	**89**	**134**	**191**	**2392**	**123**	**173**	**4.1**	**2663**	**86**
SD	*0*	*143*	*88*	*15*	*22*	*66*	*229*	*7*	*4*	*1.6*	*22*	*13*

Low Intensity Conditioning Sessions

Raw data		Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
Sprint technique						
BC	46	11	15	6.1	29	2.9
DW	46	13	16	6.9	26	3.0
GS	46	6	17	6.0	26	2.6
IM	46	10	15	6.4	23	3.2
JH	46	11	17	6.4	33	2.8
LD	46	8	12	5.4	37	2.2
MH	46	10	16	6.3	32	2.7
MH	46	15	18	6.7	30	3.0
PF	46	17	18	7.1	35	3.1
SO	46	13	17	6.4	31	2.7
TD	46	17	16	7.4	41	2.7
UK	46	11	14	6.5	29	2.7
Mean	**46**	**12**	**16**	**6.5**	**31**	**2.8**
SD	*0*	*3*	*2*	*0.5*	*5*	*0.3*

Game simulations

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Bat- 30 over												
DW	21	687	171	73	155	134	1220				1186	74
LD	60	2037	424	101	189	146	2897	148	172		3503	96
MH	48	2020	546	121	221	270	3178	144	173	2.8	2748	131
PF	16	578	122	45	78	100	923	145	170	2.4	881	48
TD	7	288	71	16	48	17	440	138	158		400	21
UK	60	1842	379	127	148	87	2583	143	177	2.0	3517	83
Mean	**35**	**1242**	**286**	**81**	**140**	**126**	**1874**	**144**	**170**	**2.4**	**2039**	**76**
SD	*24*	*807*	*191*	*44*	*66*	*84*	*1152*	*4*	*7*	*0.4*	*1385*	*38*
Bat open wicket												
GM	13.5	400	129	49	105	45	728	147	170		768	42
MH	15	492	182	29	53	91	847	165	184	2.4	864	37
PF	15	521	176	44	78	51	870	147	178		864	37
TM	12.5	459	114	34	48	32	687	151	172		723	27
VK	11	342	98	26	34	16	516	137	164	2.6	642	18
Mean	**13**	**443**	**140**	**36**	**64**	**47**	**730**	**149**	**174**	**2.5**	**772**	**32**
SD	*2*	*72*	*37*	*10*	*28*	*28*	*142*	*10*	*8*	*0.1*	*95*	*10*
Bat – scenario												
DW	24	992	185	40	30	22	1269				1418	22
GM	28	835	160	35	56	73	1159	139	175		1634	40
JH	20	788	222	50	117	115	1292			2.1	1145	56
LD	24	948	217	80	69	70	1384	147	167	1.9	1392	47
PF	28	913	150	27	87	113	1290	142	177		1631	49
TD	14	514	152	43	52	91	852	156	186	2.7	802	39
UK	9	322	36	15	34	37	444	128	155		521	19
VK	3	102	9	6	21	16	154	140	178		171	10
Mean	**19**	**677**	**141**	**37**	**58**	**67**	**981**	**142**	**173**	**2.4**	**1089**	**35**
SD	*9*	*327*	*79*	*23*	*32*	*39*	*456*	*9*	*11*	*0.4*	*540*	*16*

Game simulations

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Bat- 30 over							
DW	21	13	10	5.0		32	2.3
LD	60	13	11	4.1		37	2.6
MH	48	21	13	5.7		50	2.6
PF	16	10	10	5.0		19	2.5
TD	7	2	9	4.1		8	2.6
UK	60	8	11	5.6		34	2.4
Mean	**35**	**11**	**11**	**4.9**		**30**	**2.5**
SD	*24*	*6*	*1*	*0.7*		*15*	*0.1*
Bat open wicket							
GM	13.5	4	11	4.5		21	2.0
MH	15	8	11	4.7		15	2.5
PF	15	3	17	4.7		15	2.5
TM	12.5	3	11	4.7		11	2.5
VK	11	1	16	4.8		9	2.0
Mean	**13**	**4**	**13**	**4.7**		**14**	**2.3**
SD	*2*	*3*	*3*	*0.1*		*5*	*0.3*
Bat – scenario							
DW	24	1	22	4.5		10	2.2
GM	28	5	15	5.0		12	3.3
JH	20	9	13	5.4		26	2.2
LD	24	6	12	5.4		23	2.0
PF	28	11	10	6.4		15	3.3
TD	14	7	13	5.5		15	2.6
UK	9	4	9	4.5		10	1.9
VK	3	2	8	4.4		5	2.0
Mean	**19**	**6**	**13**	**5.1**		**15**	**2.4**
SD	*9*	*3*	*4*	*0.7*		*7*	*0.6*

Game simulations

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Fast bowl scenario												
DK	28	1086	175	67	166	177	1671	125	162	1.6	1601	76
PS	28	797	169	28	24	10	1028	124	171	2.2	1666	13
DK	9	431	76	20	57	37	621	124	154		516	24
PS	9	218	63	18	7	3	309	130	155		533	8
Mean	**19**	**633**	**121**	**33**	**64**	**57**	**907**	**126**	**161**	**1.9**	**1079**	**30**
SD	*11*	*385*	*59*	*23*	*71*	*81*	*588*	*3*	*8*	*0.4*	*641*	*31*
Fast bowler open wicket												
PS	43	1522	377	112	258	454	2723	118	147	1.3	2407	173
PS	37.5	1213	477	144	167	51	2052	124	153		2161	88
Mean	**40**	**1368**	**427**	**128**	**213**	**253**	**2388**	**121**	**150**	**1.3**	**2284**	**131**
SD	*4*	*218*	*71*	*23*	*64*	*285*	*474*	*4*	*4*		*174*	*60*
Field – 30 over												
LD	103	3751	1157	131	118	136	5293	116	156		6095	83
MH	82	3533	1198	240	154	91	5216	120	151		4802	119
MH	105	4833	578	99	175	463	6148				6157	139
PF	105	3584	1120	181	192	110	5187	113	173		6187	111
PS	105	4265	989	183	354	658	6449				6058	241
SO	105	4079	1453	277	194	132	6135	125	163		6157	144
Mean	**101**	**4008**	**1083**	**185**	**198**	**265**	**5738**	**119**	**161**		**5909**	**140**
SD	*9*	*495*	*290*	*66*	*82*	*235*	*567*	*5*	*10*		*545*	*54*

Game simulations

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fast bowler - scenario							
DK	28	12	15	5.3		35	2.2
PS	28	1	10	4.0		6	2.2
DK	9	3	12	5.5		11	2.2
PS	9	0		3.7		1	8.0
Mean	**19**	**4**	**12**	**4.6**		**13**	**3.6**
SD	*11*	*6*	*2*	*0.9*		*15*	*2.9*
Fast bowler – open wicket							
PS	43	31	15	5.7		68	2.5
PS	37.5	2	26	4.9		35	2.5
Mean	**40**	**17**	**20**	**5.3**		**53**	**2.5**
SD	*4*	*21*	*8*	*0.6*		*23*	*0*
Field – 30 over							
LD	103	10	14	5.9		27	3.1
MH	82	6	15	5.5		38	3.1
MH	105	25	19	6.2		48	2.9
PF	105	7	16	5.1		34	3.3
PS	105	37	18	6.6		87	2.8
SO	105	9	15	8.0		45	3.2
Mean	**101**	**16**	**16**	**6.2**		**47**	**3.1**
SD	*9*	*13*	*2*	*1.0*		*21*	*0.2*

Game simulations

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Field - scenario												
DW	28	946	235	66	161	131	1539				1598	75
JH	28	701	131	21	16	6	875				1669	10
LD	28	646	109	13	16	57	841	97	150		1665	15
TD	28	1312	275	61	68	17	1733	112	145		1641	39
UK	28	1008	181	16	28	36	1269	112	137		1662	18
VK	28	660	79	15	11	0	765	94	122		1674	6
DW	9	431	76	22	57	102	688				451	39
JH	9	232	47	6	0	0	285				538	2
LD	9	371	42	3	0	0	416	98	146		539	1
PF	9	240	33	2	8	0	283	108	124		538	2
TM	9	379	238	59	33	6	715	132	163		516	24
TD	9	316	35	3	3	1	358	93	114		538	1
DK	24	930	139	36	40	33	1178	110	158		1414	25
JH	24	737	120	12	16	7	892				1432	8
PF	24	1112	367	73	74	48	1674	121	166		1394	46
PS	24	818	269	69	126	63	1345	106	137		1383	58
TM	24	984	317	55	46	34	1436	118	167		1408	32
TD	24	1154	352	112	122	81	1821	111	151		1367	72
UK	24	1073	447	41	33	52	1646	136	167		1413	26
VK	24	940	198	47	30	3	1218	99	132		1419	21
DK	27	994	158	34	55	11	1252	107	147		1599	21
PF	27	1038	252	28	36	30	1384	108	151		1597	22
PS	27	960	196	23	18	16	1213	103	158		1606	14
VK	27	992	248	54	47	9	1350	98	161		1592	27
Mean	**22**	**791**	**189**	**36**	**44**	**31**	**1091**	**109**	**147**		**1277**	**25**
SD	*8*	*314*	*114*	*28*	*42*	*35*	*470*	*12*	*16*		*459*	*21*

Game simulations

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Field - scenario							
DW	28	9	15	5.6		28	2.7
JH	28	0		5.4		2	5.0
LD	28	3	19	6.7		4	3.8
TD	28	1	17	4.5		12	3.3
UK	28	3	12	5.3		8	2.3
VK	28	0		3.1		2	3.0
DW	9	9	11	5.0		17	2.3
JH	9	0		3.0		0	
LD	9	0		2.7		0	
PF	9	0		3.0		1	2.0
TM	9	1	6	4.7		8	3.0
TD	9	0		2.3		0	
DK	24	2	17	4.7		10	2.5
JH	24	1	7	3.8		4	2.0
PF	24	3	16	4.7		15	3.1
PS	24	4	16	5.1		20	2.9
TM	24	2	17	5.0		12	2.7
TD	24	5	16	5.1		26	2.8
UK	24	3	17	5.0		7	3.7
VK	24	0		4.1		8	2.6
DK	27	0		3.7		8	2.6
PF	27	1	30	5.7		6	3.7
PS	27	2	8	3.7		4	3.5
VK	27	1	9	4.3		11	2.5
Mean	**22**	**2**	**15**	**4.4**		**9**	**2.9**
SD	*8*	*3*	*6*	*1.1*		*8*	*0.7*

Game simulations

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Spin open wicket												
AN	68	3258	693	36	33	4	4024	134	153		4065	17
SM	68	3623	1000	146	98	9	4876	127	166		3980	68
Mean	**68**	**3441**	**847**	**91**	**66**	**7**	**4450**	**131**	**160**		**4023**	**43**
SD	*0*	*258*	*217*	*78*	*46*	*4*	*602*	*5*	*9*		*60*	*36*
Spin bowl scenario												
DW	27	915	248	51	52	31	1297				1590	30
LD	27	1100	407	81	65	22	1675	139	175		1577	43
UK	27	861	185	60	69	59	1234	105	137		1577	43
Mean	**27**	959	280	64	62	37	1402	122	156		1581	39
SD	*0*	125	114	15	9	19	239	24	27		8	8
Wicketkeeping 30 over												
GM	105	3106	1015	155	191	49	4516				6207	93
Mean	**105**	**3106**	**1015**	**155**	**191**	**49**	**4516**				**6207**	**93**
SD												
Wicketkeeping scenario												
GM	9	289	75	13	14	0	391	128	149		533	7
GM	24	479	8	0	0	0	487	118	136		1440	0
GM	27	457	49	3	4	12	525	112	143		1614	4
Mean	**20**	**408**	**44**	**5**	**6**	**4**	**468**	**119**	**143**		**1196**	**4**
SD	*10*	*104*	*34*	*7*	*7*	*7*	*69*	*8*	*7*		*580*	*4*

Game simulations

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Spin open wicket							
AN	68	0		3.3		2	8.5
SM	68	0		3.7		16	4.3
Mean	**68**			**3.5**		**9**	**6.4**
SD	*0*			*0.3*		*10*	*3.0*
Spin bowl scenario							
DW	27	2	16	4.6		11	2.7
LD	27	1	22	4.0		10	4.3
UK	27	5	12	5.0		16	2.7
Mean	**27**	**3**	**16**	**4.5**		**12**	**3.2**
SD	*0*	*2*	*5*	*0.5*		*3*	*0.9*
Wicketkeeping 30 over							
GM	105	2	25	4.9		30	3.1
Mean	**105**	**2**	**25**	**4.9**		**30**	**3.1**
SD							
Wicketkeeping scenario							
GM	9	0		2.9		2	3.5
GM	24	0		1.6		0	
GM	27	0		3.1		0	
Mean	**20**	**0**		**2.5**		**1**	**3.5**
SD	*10*			*0.8*		*1*	

Skill session

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Boundary fielding												
DK	12	332	120	32	25	0	509	117	136		705	15
GM	12	380	121	27	53	60	641	125	158		689	31
LD	10	361	46	6	8	5	426				595	5
MW	16	693	175	40	43	52	1003				932	29
PS	11	247	114	27	49	17	454	111	130		638	22
SE	15	446	124	31	54	70	725	125	145		866	34
TM	12	390	72	21	51	19	553	132	158		700	19
UK	12	393	112	26	59	54	644	130	157		691	28
VK	16	540	156	26	70	58	850	130	160		927	33
Mean	**13**	**420**	**116**	**26**	**46**	**37**	**645**	**124**	**149**		**749**	**24**
SD	*2*	*129*	*39*	*9*	*19*	*27*	*190*	*8*	*12*		*126*	*10*
Crouched catches												
GM	4	148	36	4	8	9	205	119	140		234	6
JH	4	77	1	0	0	0	78	118	138		240	0
MH	8	168	42	21	9	0	240	131	158		471	8
TD	4	145	12	0	0	0	157	106	131		240	0
UK	3	106	30	3	8	18	165	131	153		173	6
DK	3	127	25	0	0	0	152	132	158		179	1
GM	3	101	8	0	0	0	109	121	143		180	0
JH	3	117	18	2	0	0	137	126	144		179	1
MW	3	110	8	0	0	0	118				180	0
PS	3	103	20	0	0	0	123	119	132		180	0
SE	3	129	8	0	0	0	137	125	142		180	0
TM	3	123	18	5	7	5	158	138	159		174	6
UK	3	65	3	4	1	0	73	123	141		179	1
VK	3	86	1	0	0	0	87	117	130		180	0
Mean	**4**	**115**	**16**	**3**	**2**	**2**	**139**	**124**	**144**		**212**	**2**
SD	*1*	*28*	*13*	*6*	*4*	*5*	*47*	*8*	*10*		*79*	*3*

Skill session

Raw data		Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
Boundary fielding						
DK	12	0		3.9	6	2.5
GM	12	5	12	5.2	14	2.2
LD	10	0		3.4	2	2.5
MW	16	4	13	4.5	10	2.9
PS	11	1	17	4.1	9	2.4
SE	15	5	14	5.8	13	2.6
TM	12	1	19	4.6	7	2.7
UK	12	5	11	4.8	12	2.3
VK	16	7	8	4.1	14	2.4
Mean	**13**	**3**	**13**	**4.5**	**10**	**2.5**
SD	*2*	3	4	0.7	4	0.2
Crouched catches						
GM	4	1	9	4.1	1	6.0
JH	4	0		1.1	0	
MH	8	0		1.6	2	4.0
TD	4	0	0	1.8	0	
UK	3	1	18	4.8	1	6.0
DK	3	0		2.6	0	
GM	3	0		1.9	0	
JH	3	0		2.2	0	
MW	3	0		2.0	0	
PS	3	0		2.0	0	
SE	3	0		1.3	0	
TM	3	0		3.6	1	6
UK	3	0		2.0	1	1
VK	3	0		1.0	0	
Mean	**4**	**0**	**9**	**2.3**	**0**	**4.6**
SD	*1*		*9*	*1.1*	*1*	*2.2*

Skill session

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Fielding session												
BC	60	615	93	5	1	0	714				3598	6
DL	40	1718	338	77	64	21	2218				2361	39
DR	40	1619	273	42	50	56	2040				2368	32
GS	40	1489	191	34	45	86	1845				2368	31
GM	40	1414	232	42	40	89	1817				2365	35
KB	40	1877	370	63	82	43	2435				2357	43
LD	60	1800	189	38	63	39	2129				3566	34
MH	60	1723	183	47	77	54	2084				3560	40
PF	40	1408	194	26	65	91	1784				3567	33
TD	67	2612	415	81	163	95	3366				3948	72
Mean	**49**	**1628**	**248**	**46**	**65**	**57**	**2043**				**3006**	**37**
SD	*11*	*496*	*100*	*23*	*41*	*33*	*656*				*686*	*16*
Net batting												
CW	30	962	39	7	0	0	1008				1794	2
DH	25	887	39	0	0	0	926				1500	0
MH	10	434	27	5	0	0	466				588	2
SW	14.5	562	15	0	0	0	577				870	0
BH	19	690	13	0	0	0	703				1140	0
BG	12	284	11	0	0	0	295				720	0
JH	13.5	423	7	0	0	0	430				810	0
MC	36	1572	57	4	3	0	1636				2157	2
MH	22.3	747	26	0	0	0	773				1350	0
MJ	13	541	19	0	0	0	560				780	0
Mean	**20**	**710**	**25**	**2**	**0**	**0**	**737**				**1171**	**1**
SD	*8*	*370*	*16*	*3*	*1*	*0*	*386*				*518*	*1*

Skill session

Raw data			Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Fielding session							
BC	60	0	0	4.1		1	6.0
DL	40	2	11	6.7		18	2.2
DR	40	3	19	8.6		8	4.0
GS	40	5	17	7.3		11	2.8
GM	40	6	15	6.6		10	3.5
KB	40	3	14	7.7		17	2.5
LD	60	4	10	6.8		15	2.3
MH	60	2	27	6.7		23	1.7
PF	40	6	15	7.4		11	3.0
TD	67	9	11	6.4		36	2.0
Mean	**49**	**4**	**14**	**6.8**		**15**	**3.0**
SD	*11*	*2*	*7*	*1.2*		*10*	*1.3*
Net batting							
CW	30	0	0	3.5		1	2
DH	25	0	0	2.9		0	0
MH	10	0	0	3.5		0	0
SW	14.5	0	0	2.5		0	0
BH	19	0	0	2.6		0	0
BG	12	0	0	2.2		0	0
JH	13.5	0	0	2.3		0	0
MC	36	0	0	3.7		0	0
MH	22.3	0	0	2.7		0	0
MJ	13	0	0	2.4		0	0
Mean	**20**	**0**	**0**	**2.8**		**0**	**0**
SD	*8*	*0*	*0*	*0.5*		*0*	*0*

Skill session

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Ground in-fielding												
BC	10	308	125	12	13	4	462				593	7
DW	10	305	96	18	18	4	441				591	9
GM	10	390	214	28	29	7	668				583	17
JH	10	330	137	21	27	4	519				588	12
LD	10	302	129	18	6	5	460				594	6
MH	10	458	287	38	23	4	810				584	16
MH	10	471	127	10	5	16	629				593	7
PF	10	488	125	11	16	7	647				591	9
SO	10	510	256	59	17	0	842				579	21
TD	10	414	285	53	44	23	819				571	28
UK	10	452	207	13	7	10	689				592	8
GM	12	566	280	28	63	14	951	149	169		696	25
JH	12	516	111	32	32	86	777	140	167		692	28
MH	11	246	46	5	9	1	307	126	150		653	6
TD	15	764	301	48	36	57	1206	161	177		871	29
UK	12	336	114	20	13	4	487	142	174		711	9
DK	10	289	121	15	14	2	441	124	144		592	8
GM	15	486	378	105	79	55	1103	141	166		844	56
LD	16	583	306	35	35	10	969	142	164		940	20
PS	10	378	115	12	28	2	535	114	135		590	9
SE	15	683	276	14	15	5	993	150	163		890	10
TM	10	350	149	26	38	42	605	147	173		578	22
UK	11	428	198	30	47	31	734	150	177		636	24
VK	13	570	262	50	53	19	954	164	177		753	28
Mean	**11**	**443**	**194**	**29**	**28**	**17**	**710**	**142**	**164**		**663**	**17**
SD	*2*	*130*	*88*	*22*	*19*	*22*	*236*	*14*	*13*		*114*	*12*

Skill session

Raw data		Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Ground in-fielding							
BC	10	0	0	3.2		1	7.0
DW	10	0	0	3.3		0	
GM	10	0	0	3.6		4	4.3
JH	10	0	0	3.9		4	3.0
LD	10	0	0	3.2		2	3.0
MH	10	0	0	3.7		4	4.0
MH	10	1	16	4.7		1	7.0
PF	10	1	7	3.7		4	2.3
SO	10	0	0	3.5		9	2.3
TD	10	2	12	4.4		14	2.0
UK	10	1	10	3.5		1	8.0
GM	12	0		4.2		10	2.5
JH	12	5	17	6.4		9	3.1
MH	11	1	1	3.8		4	1.5
TD	15	3	19	7.5		8	3.6
UK	12	0		5.1		4	2.3
DK	10	0		3.2		1	8.0
GM	15	4	14	5.3		20	2.8
LD	16	1	10	4		6	3.3
PS	10	0		4.1		3	3.0
SE	15	0		3		1	10.0
TM	10	3	14	4.2		7	3.1
UK	11	2	16	5.3		8	3.0
VK	13	2	10	4.5		11	2.5
Mean	**11**	**1**	**8**	**4.2**		**6**	**4.0**
SD	*2*	*1*	*7*	*1.1*		*5*	*2.3*

Skill session

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
High catches												
BC	21	710	207	33	61	20	1031				1233	27
DW	21	585	163	36	18	4	806				1245	15
GM	21	584	219	36	64	25	928				1231	29
JH	21	594	161	29	30	11	825				1244	16
LD	21	687	208	14	18	13	940				1250	10
MH	21	764	144	33	39	18	998				1240	20
MH	21	792	108	24	44	5	973				1244	16
PF	21	800	241	43	24	38	1146				1238	22
SO	21	870	190	42	39	10	1151				1238	22
TD	21	677	230	62	63	30	1062				1223	36
UK	21	761	168	36	30	2	997				1243	17
GM	12	548	201	14	20	8	791	135	165		710	10
JH	11	455	231	45	49	72	852	151	167		625	35
MH	12	343	71	7	32	24	477	143	166		667	13
TD	11	464	178	31	42	36	751	136	168		632	24
UK	15	287	51	1	0	0	339	153	173		897	0
DK	16	525	130	35	19	7	716	128	145		945	14
GM	12	545	187	31	38	78	879	140	164		686	33
LD	12	523	292	48	26	56	945	154	178		690	29
PS	16	629	122	10	6	3	770	109	130		956	4
SE	11	437	232	35	54	33	791	156	173		632	28
TM	16	612	262	39	26	13	952	150	171		937	18
UK	16	545	158	22	19	13	757	131	169		946	13
VK	11	520	157	40	68	201	986	177	192		602	57
Mean	**17**	**594**	**180**	**31**	**35**	**30**	**869**	**143**	**166**		**981**	**21**
SD	*4*	*145*	*58*	*14*	*18*	*42*	*188*	*17*	*15*		*264*	*12*

Skill session

Raw data		Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
High catches						
BC	21	1	20	5.2	12	2.3
DW	21	0	0	4.0	6	2.5
GM	21	1	25	5.0	9	3.2
JH	21	1	11	3.7	5	3.2
LD	21	1	13	4.2	3	3.3
MH	21	1	18	4.1	6	3.3
MH	21	1	5	4.1	8	2.0
PF	21	2	19	5.5	6	3.7
SO	21	1	10	4.2	11	2.0
TD	21	2	15	5.0	14	2.6
UK	21	0	0	4.0	8	2.1
GM	12	1	8	4.0	4	2.5
JH	11	4	18	6.4	10	3.5
MH	12	2	12	5.0	6	2.2
TD	11	2	18	5.6	10	2.4
UK	15	0		2.4	0	
DK	16	1	7	3.7	6	2.3
GM	12	5	16	5.7	12	2.8
LD	12	3	19	6.4	9	3.2
PS	16	0		3.2	0	
SE	11	3	11	4.6	13	2.2
TM	16	1	13	4.7	9	2.0
UK	16	1	13	3.7	7	1.9
VK	11	10	20	7.1	18	3.2
Mean	**17**	**2**	**13**	**4.6**	**8**	**2.6**
SD	*4*	*2*	*7*	*1.1*	*4*	*0.6*

Skill session

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Net fast bowling												
BG	28	1277	313	73	121	104	1888				1613	66
JH	31	1211	326	79	151	58	1825				1791	68
MJ	20	815	376	88	123	27	1429				1111	55
BG	28	1277	313	73	121	104	1888				1613	66
JH	31	1211	326	79	151	58	1825				1791	68
MJ	20	815	376	88	123	27	1429				1111	55
Mean	**26**	**1101**	**338**	**80**	**132**	**63**	**1714**				**1505**	**63**
SD	*5*	*223*	*30*	*7*	*15*	*35*	*223*				*315*	*6*
Net spin bowling												
CW	26	1005	191	35	26	0	1257				1529	15
Mean	**26**	**1005**	**191**	**35**	**26**	**0**	**1257**				**1529**	**15**

Raw data		Sprint data			High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)	Number (#)	Mean effort duration (s)
Net fast bowling						
BG	28	12	9	6.8	40	1.7
JH	31	6	8	5.5	26	2.6
MJ	20	3	9	7.0	30	1.8
BG	28	12	9	6.8	40	1.7
JH	31	6	8	5.5	26	2.6
MJ	20	3	9	7.0	30	1.8
Mean	**26**	**7**	**9**	**6.4**	**32**	**2.0**
SD	*5*	*4*	*1*	*0.7*	*6*	*0.5*
Net spin bowling						
CW	26	0	0	4.6	8	1.9
Mean	**26**	**0**	**0**	**4.6**	**0**	**0**

Skill session

Raw data		Distance (m) covered						Heart rate (bpm)		Lactate	Time (s) spent	
Player	Duration (min)	Walking	Jogging	Running	Striding	Sprinting	Total Distance	Mean	Max	(mMol/L) Peak	Walking & Jogging	Running, Striding, Sprinting
Partner throwing												
BC	9	339	32	1	2	0	374				540	0
DW	9	305	36	1	0	0	342				539	1
GM	9	375	68	6	2	0	451				537	3
JH	9	230	8	0	0	0	238				540	0
LD	9	370	40	0	0	0	410				540	0
MH	9	363	31	0	0	0	394				540	0
MH	9	295	18	0	0	0	313				540	0
PF	9	371	97	8	6	3	485				534	6
SO	9	249	21	0	0	0	270				540	0
TD	9	359	65	1	4	0	429				539	1
UK	9	272	26	5	1	0	304				538	2
GM	8	332	43	0	0	0	375	108	120		480	0
JH	9	449	75	5	4	12	545	106	121		444	6
MH	8	168	42	21	9	0	240	132	148		470	8
TD	8	367	71	8	13	6	465	109	127		473	6
UK	9	323	149	22	20	23	537	129	144		522	18
DK	9	396	25	1	3	0	425	143	159		538	2
GM	9	295	20	1	0	0	316	123	145		540	0
LD	9	459	108	6	7	0	580	148	167		536	3
MW	9	465	57	3	0	0	525				539	1
PS	9	373	16	0	0	0	389	113	129		540	0
SE	9	353	48	6	1	0	408	118	134		539	1
TM	9	344	126	23	8	0	501	157	168		529	10
UK	9	346	5	0	0	0	351	133	150		540	0
VK	9	420	15	0	2	1	438	119	132		539	1
Mean	**9**	**345**	**50**	**5**	**3**	**2**	**404**	**126**	**142**		**526**	**3**
SD	*0*	*70*	*38*	*7*	*5*	*5*	*95*	*16*	*16*		*27*	*4*

Skill session

Raw data		Sprint data				High Intensity Efforts data	
Player	Duration (min)	Number (#)	Mean distance (m)	Max speed ($m.s^{-1}$)		Number (#)	Mean effort duration (s)
Partner throwing							
BC	9	0		1.8		0	
DW	9	0		1.9		0	
GM	9	0		3.3		1	3.0
JH	9	0		1.3		0	
LD	9	0		1.9		0	
MH	9	0		2.5		0	
MH	9	0		1.6		0	
PF	9	1	3	3.2		3	2.0
SO	9	0		2.2		0	
TD	9	0		3.0		0	
UK	9	0		2.2		1	2.0
GM	8	0		2.6		0	
JH	9	1	12	5.6		1	6.0
MH	8	0		4.0		2	4.0
TD	8	1	6	3.7		2	3.0
UK	9	2	12	5.1		6	3.0
DK	9	0		2.3		0	
GM	9	0		2.0		0	
LD	9	0		2.8		0	
MW	9	0		2.1		0	
PS	9	0		1.8		0	
SE	9	0		2.8		0	
TM	9	0		3.3		3	3.3
UK	9	0		1.4		0	
VK	9	0		2.0		0	
Mean	**9**	**0**	**8**	**2.7**		**1**	**3.3**
SD	*0*	*1*	*4*	*1.1*		*1*	*1.1*

Study 9: Partial Heat Acclimation

Player	Age (y)	Height (cm)	Mass (kg)	Sum 7 skinfolds (mm)	Est. Body Surface Area (m^2)
Control					
AG	19.3	176.0	67.80	82.9	1.83
WP	22.1	175.5	77.95	58.4	1.94
GS	22.3	178.0	90.75	151.1	2.09
CS	19.6	182.5	82.65	64.0	2.05
LT	19.7	187.0	95.70	103.8	2.22
RE	29.2	195.2	95.30	64.6	2.28
Mean	22.0	182.4	85.03	87.5	2.07
SD	*3.7*	*7.7*	*11.00*	*35.4*	*0.17*
ACC					
SN	27.6	187.0	83.20	94.2	2.09
AK	23.5	190.0	87.95	68.3	2.16
BM	21.7	190.0	86.30	41.4	2.14
CP	33.1	178.0	79.15	91.6	1.97
ST	22.6	179.5	82.75	81.4	2.02
RC	22.6	174.9	67.60	46.9	1.82
Mean	25.2	183.2	81.16	70.6	2.03
SD	*4.4*	*6.6*	*7.31*	*22.5*	*0.13*

Baseline testing

Player	USG	HR Pre 2min (bpm)	HR 5min (bpm)	HR 10min (bpm)	HR 15min (bpm)	HR 20min (bpm)	HR 25min (bpm)	HR 30min (bpm)	HR Post 2min (bpm)	Na+	K+	Cl-
Control												
AG	1.003	88	173	172	176	182	189	186	152	59.5	9.4	36.5
WP	1.006	63	145	147	146	156	155	158	116	45.5	4.6	26.5
GS	1.023	70	137	143	150	154	159	163	136	38.5	4.7	27.0
CS	1.024	92	150	153	163	168	170	172	135	70.0	6.0	50.5
LT	1.019	120	163	175	179	180	182	190	149	56.5	5.5	39.5
RE	1.021	90	157	160	163	165	170	170	126	35.0	5.7	17.0
Mean	1.016	87	154	158	163	168	171	173	136	50.8	6.0	32.8
SD	*0.009*	*20*	*13*	*13*	*13*	*12*	*13*	*13*	*14*	*13.5*	*1.8*	*11.8*
ACC												
SN	1.004	88	156	160	172	176	184	185	150	98.5	5.3	67.5
AK	1.016	75	143	154	160	165	169	172	137	61.0	7.2	40.5
BM	1.002	76	170	173	178	183	187	190	153	74.5	6.5	49.5
CP	1.017	86	160	167	173	178	181	184	149	80.5	5.7	54.5
ST	1.016	80	159	162	166	169	172	176	151	77.0	5.8	51.0
RC	1.028	78	133	138	150	153	157	164	119	75.0	7.7	45.0
Mean	1.014	81	154	159	167	171	175	179	143	77.8	6.4	51.3
SD	*0.010*	*5*	*13*	*12*	*10*	*11*	*11*	*10*	*13*	*12.1*	*0.9*	*9.3*

Baseline testing (Cont)

Player	Core Temp Pre (°C)	Core Temp 5min (°C)	Core Temp 10min (°C)	Core Temp 15min (°C)	Core Temp 20min (°C)	Core Temp 25min (°C)	Core Temp 30min (°C)	Core Temp Post 2min (°C)
Control								
AG	37.88	37.96	38.04	38.12	38.2	38.28	38.36	38.36
WP	37.18	37.31	37.44	37.57	37.69	37.82	37.95	37.96
GS	37.96							
CS	37.45	37.56	37.85	38.09	38.37	38.63	38.91	39.03
LT	37.29	37.92	38.06	38.23	38.45	38.67	38.89	38.99
RE	37.53	37.98	38.31	38.58	38.78	38.95	39.13	39.12
Mean	37.5	37.7	37.9	38.1	38.3	38.5	38.6	38.7
SD	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*
ACC								
SN	37.34	38.08	38.06	38.86			39.03	39.08
AK	37.57	37.75	37.94	38.12	38.30	38.49	38.67	38.73
BM	37.34	38.08	38.58	38.52	38.95	38.88	38.99	39.32
CP	37.59	37.76	38.16	38.44	38.70	38.96	39.14	39.20
ST	37.57	37.73	38.03	38.32	38.56	38.77	39.02	39.08
RC								
Mean	37.5	37.9	38.2	38.5	38.6	38.8	39.0	39.1
SD	*0.1*	*0.2*	*0.3*	*0.3*	*0.3*	*0.2*	*0.2*	*0.2*

Baseline testing (Cont)

Player	Sensation Pre 2min	Sensation 10min	Sensation 20min	Sensation 30min	Comfort Pre 2min	Comfort 10min	Comfort 20min	Comfort 30min	Mass Pre (kg)	Mass Post (kg)	Fluid intake (ml)	Sweat rate (L/hr)
Control												
AG	8.0	9.0	10.0	11.0	1.5	2.5	3.5	3.5	67.80	67.55	202	0.90
WP	8.0	9.0	10.0	10.0	1.0	2.0	2.0	3.0	77.95	77.40	0	1.10
GS	8.0	10.0	10.0	10.0	1.0	2.0	3.0	3.0	90.75	90.00	0	1.50
CS	7.0	10.0	10.0	11.0	1.0	2.0	2.0	3.0	82.65	82.10	196	1.49
LT	8.0	10.0	11.0	11.0	1.0	2.0	3.0	3.0	95.70	94.80	0	1.80
RE	9.0	10.0	10.5	10.5	1.0	1.0	2.0	2.0	95.30	94.60	0	1.40
Mean	8.0	9.7	10.3	10.6	1.1	1.9	2.6	2.9	85.0	84.4	66	1.4
SD	*0.6*	*0.5*	*0.4*	*0.5*	*0.2*	*0.5*	*0.7*	*0.5*	*11.0*	*10.8*	*103*	*0.3*
ACC												
SN	7.0	9.0	10.0	11.0	1.0	2.0	3.0	3.5	83.20	82.60	0	1.20
AK	8.0	9.0	10.0	11.0	1.0	2.0	3.0	4.0	87.95	87.35	360	1.92
BM	7.0	8.0	9.0	10.0	1.0	1.0	2.0	2.0	86.30	85.65	0	1.30
CP	6.0	8.0	9.0	10.0	1.0	1.0	2.0	3.0	79.15	78.75	122	1.04
ST	7.0	9.0	10.0	11.0	1.0	2.0	3.0	3.0	82.75	82.15	28	1.26
RC	7.0	9.0	10.0	10.0	1.0	2.0	3.0	3.0	67.60	67.25	160	1.02
Mean	7.0	8.7	9.7	10.5	1.0	1.7	2.7	3.1	81.2	80.6	112	1.3
SD	*0.6*	*0.5*	*0.5*	*0.5*	*0.0*	*0.5*	*0.5*	*0.7*	*7.3*	*7.2*	*139*	*0.3*

Baseline testing (Cont)

Player	Skin Temp Pre (°C)	Skin Temp 5min (°C)	Skin Temp 10min (°C)	Skin Temp 15min (°C)	Skin Temp 20min (°C)	Skin Temp 25min (°C)	Skin Temp 30min (°C)	Skin Temp Post 2min (°C)	Lactate Post 2min (mmol/L)
Control									
AG	28.1	29.8	30.7	31.9	32.5	33.3	33.4	35.2	1.7
WP	31.8	31.8		32.9	34.7	35	35.5	36.3	1.9
GS	29.4	32	34.8	35.2	35.1	34.8	36.1	36.2	1.6
CS	32.4	32.6	33.2	33.2	34.2	34.6	34.7	36.8	3.1
LT	31.1	31.7	33.7	34	34.9	34.8	36.1	36.8	2.1
RE	33.2	34.1	36.6	37.1	37.1	37.5	37.3	38.0	2.2
Mean	31.0	32.0	33.8	34.1	34.8	35.0	35.5	36.6	2.1
SD	*1.9*	*1.4*	*2.2*	*1.9*	*1.5*	*1.4*	*1.3*	*0.9*	*0.5*
ACC									
SN	30.1	29.8	31.1	33.3	35.2	35.7	36.7	36.8	5.6
AK	31.8	34.2	34.8	35.4	35.8	36.2	36.6	36.6	2.3
BM	32.4	33.5	34.8	35.7	36.3	36.5	36.8	37.0	5.0
CP	33.0	31.8	32.0	32.6	33.8	34.7	34.8	35.7	1.8
ST	31.6	32.1	33.0	33.1	33.6	33.7	33.2	32.9	2.9
RC	31.1	33.4	33.1	33.4	33.4	33.4	34.5	35.9	2.7
Mean	31.7	32.5	33.1	33.9	34.7	35.0	35.4	35.8	3.4
SD	*1.0*	*1.6*	*1.5*	*1.3*	*1.2*	*1.3*	*1.5*	*1.5*	*1.5*

Baseline – Repeated run-3 sprints

Player	Sprint 1 (s)	Sprint 2 (s)	Sprint 3 (s)	Sprint 4 (s)	Sprint 5 (s)	Sprint 6 (s)	Lactate Post 3min (mmol/L)
Control							
AG							
WP	10.16	10.70	10.60	11.28	10.87	10.72	12.9
GS	10.47	10.96	11.85	11.97	13.00	12.38	11.1
CS							
LT	10.61	10.76	11.30	11.50	11.74	11.35	16.0
RE	10.85	11.51	11.44	11.97	11.88	11.88	11.7
Mean	10.52	10.98	11.30	11.68	11.87	11.58	12.9
SD	*0.29*	*0.37*	*0.52*	*0.35*	*0.87*	*0.71*	*2.2*
ACC							
SN	10.56	11.01	11.66	12.21	12.74	12.61	12.0
AK	10.29	10.57	10.89	11.17	11.44	11.71	12.7
BM	10.89	11.14	11.18	11.48	11.65	11.67	13.0
CP	11.05	11.37	12.08	12.37	12.26	12.53	11.6
ST	10.18	10.72	10.95	11.83	12.25	12.16	14.9
RC	9.66	10.43	10.70	10.87	10.66	10.30	17.6
Mean	10.44	10.87	11.24	11.66	11.83	11.83	13.6
SD	*0.51*	*0.36*	*0.53*	*0.59*	*0.74*	*0.85*	*2.3*

Post testing

Player	USG	HR Pre 2min (bpm)	HR 5min (bpm)	HR 10min (bpm)	HR 15min (bpm)	HR 20min (bpm)	HR 25min (bpm)	HR 30min (bpm)	HR Post 2min (bpm)	Na+	K+	Cl-
Control												
AG	1.013	68	154	164	164	169	174	172	127	56.5	7.3	37.0
WP	1.006	57	130	142	147	152	160	160	115	36.0	4.6	19.5
GS	1.027	58	152	160	151	158	159	161	123	27.0	5.3	19.5
CS	1.026	76	148	151	152	157	159	162	122	58.5	7.7	45.5
LT	1.030	95	150	155	163	168	177	177	143	47.0	6.5	37.5
RE	1.021	90	149	156	160	162	164	167	119	22.5	5.0	18.0
Mean	1.021	74	147	155	156	161	166	167	125	41.3	6.0	29.5
SD	*0.009*	*16*	*9*	*8*	*7*	*7*	*8*	*7*	*10*	*15.1*	*1.3*	*11.9*
ACC												
SN	1.012	66	158	165	173	177	182	185	138	70.5	5.2	44.0
AK	1.017	83	135	147	152	158	160	162	117	56.5	6.7	39.5
BM	1.005	80	159	168	169	176	179	185	133	67.5	6.0	43.0
CP	1.014	85	158	159	157	159	164	166	125	50.0	4.3	32.0
ST	1.004	79	143	158	158	161	162	161	128	60.0	5.1	38.5
RC	1.024	74	129	134	138	143	148	149	102	76.0	5.5	42.0
Mean	1.013	78	147	155	158	162	166	168	124	63.4	5.4	39.8
SD	*0.008*	*7*	*13*	*13*	*13*	*13*	*13*	*14*	*13*	*9.6*	*0.8*	*4.4*

Post testing (Cont)

Player	Core Temp Pre (°C)	Core Temp 5min (°C)	Core Temp 10min (°C)	Core Temp 15min (°C)	Core Temp 20min (°C)	Core Temp 25min (°C)	Core Temp 30min (°C)	Core Temp Post 2min (°C)
Control								
AG								
WP	36.71	37.03	37.17	37.35	37.58	37.88	38.13	38.19
GS	37.13	37.34	37.38	37.51	37.65	37.82	38.01	38.19
CS	37.11	37.36						
LT								
RE	37.99	38.16	38.39	38.68	38.98	39.09	39.28	39.29
Mean	37.2	37.5	37.6	37.8	38.1	38.3	38.5	38.6
SD	*0.5*	*0.5*	*0.7*	*0.7*	*0.8*	*0.7*	*0.7*	*0.6*
ACC								
SN	37.78	37.86	38.15	38.23	38.29	38.55	38.8	38.87
AK	36.91	37.08	37.13	37.3	37.55			
BM	37.13	37.53	38.13	38.47	38.77	39.06	39.32	39.39
CP	37.51	37.55	37.88	38.16	38.33	38.48	38.63	38.68
ST								
RC								
Mean	37.3	37.5	37.8	38.0	38.2	38.7	38.9	39.0
SD	*0.4*	*0.3*	*0.5*	*0.5*	*0.5*	*0.3*	*0.4*	*0.4*

Post testing (Cont.)

Player	Sensation Pre 2min	Sensation 10min	Sensation 20min	Sensation 30min	Comfort Pre 2min	Comfort 10min	Comfort 20min	Comfort 30min	Mass Pre (kg)	Mass Post (kg)	Fluid intake (ml)	Sweat rate (L/hr)
Control												
AG	7.0	8.0	9.0	9.0	1.0	1.5	2.5	2.0	68.30	67.90	132	1.06
WP	7.5	9.0	9.0	10.0	1.0	1.0	2.0	3.0	79.35	78.65	0	1.40
GS	6.0	8.0	9.0	10.0	1.0	1.0	2.0	2.0	90.25	89.60	0	1.30
CS	7.0	8.0	9.0	9.0	1.0	1.0	2.0	2.0	81.85	81.25	126	1.45
LT	7.0	8.0	9.0	10.0	1.0	1.0	2.0	3.0	95.25	94.40	0	1.70
RE	7.0	9.0	9.0	9.0	1.0	1.0	2.0	2.0	94.45	93.70	0	1.50
Mean	6.9	8.3	9.0	9.5	1.0	1.1	2.1	2.3	84.9	84.3	43	1.4
SD	*0.5*	*0.5*	*0.0*	*0.5*	*0.0*	*0.2*	*0.2*	*0.5*	*10.4*	*10.3*	*67*	*0.2*
ACC												
SN	7.0	7.0	8.0	8.0	1.0	1.0	1.0	2.0	83.85	83.20	42	1.38
AK	7.0	9.0	11.0	10.0	1.0	2.0	2.0	3.0	88.45	88.05	360	1.52
BM	5.0	7.0	8.0	8.0	1.0	1.0	2.0	2.0	85.60	84.90	0	1.40
CP	7.0	8.0	9.0	10.0	1.0	1.0	2.0	2.0	78.35	78.10	234	0.97
ST	6.0	8.0	9.0	9.0	1.0	2.0	2.0	2.0	83.50	82.95	0	1.10
RC	7.0	9.0	10.0	10.0	1.0	2.0	3.0	3.0	67.65	67.30	128	0.96
Mean	6.5	8.0	9.2	9.2	1.0	1.5	2.0	2.3	81.2	80.8	127	1.2
SD	*0.8*	*0.9*	*1.2*	*1.0*	*0.0*	*0.5*	*0.6*	*0.5*	*7.4*	*7.3*	*145*	*0.2*

Post testing (Cont.)

Player	Skin Temp Pre (°C)	Skin Temp 5min (°C)	Skin Temp 10min (°C)	Skin Temp 15min (°C)	Skin Temp 20min (°C)	Skin Temp 25min (°C)	Skin Temp 30min (°C)	Skin Temp Post 2min (°C)	Lactate Post 2min (mmol/L)
Control									
AG	31.4	32.6	33.4	33.7	34.3	34.2	34.6	35.4	1.3
WP	32	33	33.1	34	34.5	34.7	34.9	36.2	2.9
GS	30.1	31	32.2	32.5	33.4	34.1	34.8	35.8	1.8
CS	30.5	32	32.7	33.9	34	34.3	33.7	36.1	2.7
LT	29.6	32.1	33.5	32.8	33.1	34	35.8	36.9	1.6
RE	31.0	32.3	35.2	36.2	36.7	37.1	36.9	33.9	2.0
Mean	30.8	32.2	33.4	33.9	34.3	34.7	35.1	35.7	2.1
SD	*0.9*	*0.7*	*1.0*	*1.3*	*1.3*	*1.2*	*1.1*	*1.0*	*0.6*
ACC									
SN									5.0
AK	34.2	34.7	35.7	36.2	36.5	36.8	37	37.3	1.6
BM	34	34.8	35.3	36.1	36.8	37.3	37.5	37.6	3.9
CP	31.3	31.8	33.7	34.9	35.5	36	36.5	36.6	1.7
ST	34	34.4	35.8	36.3	36.4	36.3	36.7	37.2	2.3
RC	31.3	31	31.1	32.3	33	32.2	32.4	34.8	2.2
Mean	33.0	33.3	34.3	35.2	35.6	35.7	36.0	36.7	2.8
SD	*1.5*	*1.8*	*2.0*	*1.7*	*1.6*	*2.0*	*2.1*	*1.1*	*1.4*

Post testing – Repeated run-3 sprints

Player	Sprint 1 (s)	Sprint 2 (s)	Sprint 3 (s)	Sprint 4 (s)	Sprint 5 (s)	Sprint 6 (s)	Lactate Post 3min (mmol/L)
Control							
AG							
WP	10.07	10.31	10.59	10.78	10.60	10.66	13.3
GS	10.61	11.22	11.84	12.41	12.17	12.27	9.8
CS							
LT							
RE	10.97	11.61	11.64	11.79	11.91	12.00	10.7
Mean	10.55	11.05	11.36	11.66	11.56	11.64	11.3
SD	*0.45*	*0.67*	*0.67*	*0.82*	*0.84*	*0.86*	*1.8*
ACC							
SN	10.99	11.64	11.85	12.44	12.57	12.64	10.0
AK	10.15	10.41	10.91	10.90	11.11	11.39	13.2
BM	10.65	11.12	11.10	11.37	11.48	11.47	14.0
CP	10.93	11.33	11.68	11.87	11.92	12.11	13.3
ST	9.94	10.61	10.80	11.36	11.48	11.76	15.2
RC	10.50	10.80	10.88	11.20	11.14	11.21	15.1
Mean	10.53	10.99	11.20	11.52	11.62	11.76	13.5
SD	*0.42*	*0.46*	*0.45*	*0.55*	*0.55*	*0.53*	*1.9*

Study 10: Heat Acclimation versus Acclimatization

Player	Age (y)	Height (cm)	Mass (kg)	Sum 7 skinfolds (mm)	Est. Body Surface Area (m^2)
BRIS					
TC	22.7	187	92.90	70	2.19
PG	22.8	202	86.85	50	2.25
TT	18.8	176	75.00	55	1.91
CD	26.0	193	99.15	80	2.30
JF	19.3	184	82.70	60	2.06
Mean	21.9	188.4	87.3	63.0	2.14
SD	*2.9*	*9.8*	*9.3*	*12.0*	*0.16*
CHEN					
AM	18.2	180	83.75	40	2.04
RQ	27.0	193	89.40	63	2.20
JD	39.3	180	78.10	80	1.98
AK	32.9	183	87.90	85	2.10
KR	18.5	191	83.40	66	2.12
MH	20.9	181	84.30	70	2.05
JF	18.7	189	72.55		1.98
TB	18.7	187	92.55		2.18
TA	18.9	186	93.95	73	2.19
Mean	23.7	185.6	85.1	68.1	2.09
SD	*7.7*	*4.9*	*6.8*	*14.6*	*0.09*

Baseline testing

Player	USG	HR Pre 2min (bpm)	HR 5min (bpm)	HR 10min (bpm)	HR 15min (bpm)	HR 20min (bpm)	HR 25min (bpm)	HR 30min (bpm)	HR Post 2min (bpm)	Na+	K+	Cl-
BRIS												
TC	1.019	76	140	143	146	152	156	159	118	85.5	5.8	65.5
PG	1.023	116	168	175	179	181	182	185	145	65.5	7.7	47.5
TT	1.024	71	138	150	158	155	164	164	117	72.5	7.2	53.5
CD		112	161	170	175	180	183	181	165	93.5	11.7	70.5
JF	1.027	112	161	168	173	176	177	181	133	81.0	7.6	63.0
Mean	1.023	97	154	161	166	169	172	174	136	79.6	8.0	60.0
SD	*0.003*	*22*	*14*	*14*	*14*	*14*	*12*	*12*	*20*	*10.9*	*2.2*	*9.3*
CHEN												
AM	1.023	87	140	153	159	163	167	170	128	61.0	9.1	45.5
RQ	1.025	82	126	137	143	148	156	162	135	100.0	9.2	78.5
JD	1.018	81	144	155	159	160	162	168	136	70.0	5.3	46.5
AK	1.019	70	139	146	153	157	165	169	138	101.0	11.5	67.5
KR	1.024	91	141	149	154	156	156	163	130	75.5	5.9	52.0
MH	1.020	58	127	139	140	144	142	146	113	60.0	9.3	43.5
JF	1.025	85	146	152	150	156	159	164	122	120.5	18.7	101.5
TB	1.002	82	143	150	156	162	162	167	140	51.5	6.6	33.5
TA	1.027	80	130	140	145	152	156	160	122	79.0	10.7	53.5
Mean	1.020	80	137	147	151	155	158	163	129	79.8	9.6	58.0
SD	*0.008*	*10*	*8*	*7*	*7*	*6*	*7*	*7*	*9*	*22.8*	*4.0*	*21.1*

Baseline testing (Cont)

Player	Core Temp Pre (°C)	Core Temp 5min (°C)	Core Temp 10min (°C)	Core Temp 15min (°C)	Core Temp 20min (°C)	Core Temp 25min (°C)	Core Temp 30min (°C)	Core Temp Post 2min (°C)
BRIS								
TC	36.96	37.13	37.4	37.68	37.95	38.23	38.43	38.56
PG	37.71	37.93	38.2	38.33	38.58	38.73	38.92	39.03
TT	37.35	37.50	37.65	37.80	37.97	38.14	38.32	38.38
CD	37.53	37.91	38.28	38.55	38.77	39.01	39.32	39.26
JF								
Mean	37.39	37.62	37.88	38.09	38.32	38.53	38.75	38.81
SD	*0.32*	*0.38*	*0.43*	*0.42*	*0.42*	*0.41*	*0.46*	*0.41*
CHEN								
AM	37.18	37.18	37.40	37.61	37.84	38.13	38.27	38.38
RQ								
JD	36.81	37.24	37.62	37.84	38.08	38.24	38.45	38.53
AK	37.94	38.13	38.41	38.60	38.80	38.97	39.16	39.24
KR	37.39	37.56	37.76	38.06	38.07	38.19	38.39	38.43
MH	36.75	36.95	37.13	37.15	37.35	37.50	37.48	37.48
JF								
TB	37.09	37.27	37.38	37.62	37.82	38.00	38.18	38.18
TA	37.06	37.32	37.49	37.65	37.85	38.07	38.31	38.38
Mean	37.17	37.38	37.60	37.79	37.97	38.16	38.32	38.37
SD	*0.40*	*0.38*	*0.41*	*0.45*	*0.44*	*0.43*	*0.49*	*0.52*

Baseline testing (Cont)

Player	Sensation Pre 2min	Sensation 10min	Sensation 20min	Sensation 30min	Comfort Pre 2min	Comfort 10min	Comfort 20min	Comfort 30min	Mass Pre (kg)	Mass Post (kg)	Fluid intake (ml)	Sweat rate (L/hr)
BRIS												
TC	7.0	8.0	9.0	9.0	1.0	1.5	2.0	2.0	92.90	92.50	312	1.42
PG	7.0	9.5	10.0	11.0	1.0	2.0	3.0	3.5	86.85	86.75	740	1.68
TT	7.0	9.0	10.0	10.0	1.0	1.0	1.0	2.0	75.00	74.60	200	1.20
CD	7.0	8.0	9.5	9.0	1.0	1.0	2.5	4.0	99.15	98.25	48	1.90
JF	8.0	9.0	10.0	11.0	1.0	2.5	3.0	4.0	82.70	82.70	720	1.44
Mean	7.2	8.7	9.7	10.0	1.0	1.6	2.3	3.1	87.32	86.96	404	1.53
SD	*0.4*	*0.7*	*0.4*	*1.0*	*0.0*	*0.7*	*0.8*	*1.0*	*9.28*	*9.07*	*312*	*0.27*
CHEN												
AM	7.0	8.0	9.0	10.0	1.0	1.0	1.0	2.0	83.75	83.35	362	1.52
RQ	8.0	9.0	9.0	10.0	1.5	2.0	2.0	2.5	89.40	89.25	356	1.01
JD	5.0	9.0	10.0	11.0	1.0	2.0	3.0	3.0	78.10	77.85	364	1.23
AK	6.0	9.0	9.0	9.0	1.0	1.5	2.5	3.0	87.90	87.75	361	1.02
KR	8.0	10.0	11.0	12.0	2.0	3.0	3.0	5.0	83.40	82.95	266	1.43
MH	7.0	8.0	9.0	10.0	1.0	1.0	2.0	2.0	84.30	84.20	366	0.93
JF	6.0	9.0	10.0	11.0	1.0	3.0	3.0	4.0	72.55	72.25	230	1.06
TB	7.0	9.0	9.0	9.5	1.0	1.0	1.0	1.0	92.55	92.05	198	1.40
TA	7.0	8.0	9.0	9.0	1.0	2.0	3.0	3.0	93.95	93.70	418	1.34
Mean	6.8	8.8	9.4	10.2	1.2	1.8	2.3	2.8	85.10	84.82	325	1.22
SD	*1.0*	*0.7*	*0.7*	*1.0*	*0.4*	*0.8*	*0.8*	*1.2*	*6.82*	*6.82*	*74*	*0.22*

Baseline testing (Cont)

Player	Skin Temp Pre (°C)	Skin Temp 5min (°C)	Skin Temp 10min (°C)	Skin Temp 15min (°C)	Skin Temp 20min (°C)	Skin Temp 25min (°C)	Skin Temp 30min (°C)	Skin Temp Post 2min (°C)	Lactate Post 2min (mmol/L)
BRIS									
TC	29.9	32.6	32.7	33.5	33.7	33.9	33.9	34.6	1.6
PG	32.4	32.5	31.9	32.4	33.0	33.1	33.3	33.7	3.0
TT	30.1	29.4	29.6	29.9	31.2	32.1	32.7	32.8	1.2
CD	30.9	30.2	30.5	31.7	32.1	32.6	31.5	32.6	2.8
JF	29.6	31.5	32.8	33.8	32.5	32.7	33.6	32.9	1.4
Mean	30.6	31.2	31.5	32.3	32.5	32.9	33.0	33.3	2.0
SD	*1.1*	*1.4*	*1.4*	*1.6*	*0.9*	*0.7*	*0.9*	*0.8*	*0.8*
CHEN									
AM	31.4	31.4	33.4	33.8	34.5	33.9	33.8	33.8	0.9
RQ	31.2	30.3	32.5	33.2	33.1	33.2	33.7	34.5	1.1
JD	29.5	30.5	31.3	32.8	32.8	33.2	33.6	34.8	1.7
AK	29.4	30.7	31.8	32.0	33.0	32.1	32.1	33.3	1.2
KR	30.7	32.2	32.4	33.1	33.6	34.3	34.6	34.7	1.1
MH	31.2	31.1	33.7	34.3	34.4	34.3	34.0	33.8	1.2
JF	31.1	32.1	33.2	32.6	33.3	33.5	33.7	34.3	1.3
TB	31.1	31.1	33.1	33.8	33.9	34.0	34.0	37.1	1.8
TA	24.9	29.9	31.5	32.1	32.4	32.2	32.6	33.3	1.6
Mean	30.1	31.0	32.5	33.1	33.4	33.4	33.6	34.4	1.3
SD	*2.1*	*0.8*	*0.9*	*0.8*	*0.7*	*0.8*	*0.8*	*1.2*	*0.3*

Baseline – Repeated run-3 sprints

Player	Sprint 1 (s)	Sprint 2 (s)	Sprint 3 (s)	Sprint 4 (s)	Sprint 5 (s)	Sprint 6 (s)	HR 0s (bpm)	HR 30s (bpm)	HR 60s (bpm)	HR 90s (bpm)	HR 120s (bpm)
BRIS											
TC	9.66	10.08	10.44	10.54	10.76	10.85	175	167	152	130	130
PG	10.00	10.17	10.45	10.77	10.72	10.77	186	181	171	164	153
TT	10.30	11.11	11.03	11.10	11.35	11.01	195	192	179	163	153
CD	11.33	11.52	11.69	12.13	12.36	12.27	177	174	167	158	147
JF	10.97	10.97	11.31	11.61	11.68	12.00	188	182	167	153	151
Mean	10.45	10.77	10.98	11.23	11.37	11.38	184	179	167	154	147
SD	*0.69*	*0.62*	*0.54*	*0.64*	*0.68*	*0.70*	*8*	*9*	*10*	*14*	*10*
CHEN											
AM	9.93	10.34	10.39	10.51	10.48	10.55	180	173	158	148	136
RQ	10.74	10.53	11.15	11.39	11.39	11.24	182	175	154	138	131
JD	10.64	11.16	11.49	11.71	11.67	11.72	183	179	167	138	131
AK	10.36	10.75	11.25	11.45	11.59	11.63	181	174	163	152	139
KR											
MH	10.49	11.02	11.22	11.42	11.58	11.32	178	165	141	130	123
JF											
TB	10.87	11.84	12.11	12.25	11.79	11.99	187	179	167	151	140
TA											
Mean	10.51	10.94	11.27	11.46	11.42	11.41	182	174	158	143	133
SD	*0.33*	*0.53*	*0.56*	*0.56*	*0.48*	*0.50*	*3*	*5*	*10*	*9*	*6*

Post testing

Player	USG	HR Pre 2min (bpm)	HR 5min (bpm)	HR 10min (bpm)	HR 15min (bpm)	HR 20min (bpm)	HR 25min (bpm)	HR 30min (bpm)	HR Post 2min (bpm)	Na+	K+	Cl-
BRIS												
TC	1.004	65	134	140	147	150	153	156	111	87.5	5.1	63.0
PG	1.017	93	166	169	174	175	179	182	143	53.5	7.0	36.5
TT	1.011	72	143	148	152	156	157	164	129	79.5	11.6	61.0
CD	1.015	65	153	150	166	159	171	180	156	63.0	7.6	43.0
JF	1.016	80	150	165	164	169	174	179	130	68.5	5.2	45.0
Mean	1.013	75	149	154	161	162	167	172	134	70.4	7.3	49.7
SD	*0.005*	*12*	*12*	*12*	*11*	*10*	*11*	*12*	*17*	*13.4*	*2.7*	*11.7*
CHEN												
AM	1.005	62	135	145	150	153	160	160	110	47.5	5.5	34.0
RQ	1.008	52	129	137	137	141	146	151	109	48.0	4.2	29.0
JD	1.003	68	147	155	160	161	170	173	141	70.0	4.8	48.5
AK	1.013	56	140	149	152	157	158	163	118	80.5	5.9	53.5
KR	1.014	69	137	138	145	149	148	156	123	58.0	4.5	35.5
MH	1.013	86	130	139	143	147	150	153	117	65.0	6.6	49.0
JF	1.016	80	142	148	158	153	157	164	126	55.0	6.6	43.5
TB	1.010	94	155	163	166	173	178	180	155	74.5	5.7	55.0
TA	1.020	85	143	157	159	164	169	174	130	51.0	5.9	36.0
Mean	1.011	72	140	148	152	155	160	164	125	61.1	5.5	42.7
SD	*0.005*	*15*	*8*	*9*	*9*	*10*	*11*	*10*	*15*	*12.0*	*0.9*	*9.4*

Post testing (Cont)

Player	Core Temp Pre (°C)	Core Temp 5min (°C)	Core Temp 10min (°C)	Core Temp 15min (°C)	Core Temp 20min (°C)	Core Temp 25min (°C)	Core Temp 30min (°C)	Core Temp Post 2min (°C)
BRIS								
TC	37.11	37.18	37.24	37.36	37.56	37.71	37.82	37.91
PG								
TT	37.08	37.69	37.72	37.79	37.95	38.19	38.34	38.4
CD	37.61	37.7	37.88	38.08	38.3	38.56	38.81	38.91
JF								
Mean	37.27	37.52	37.61	37.74	37.94	38.15	38.32	38.41
SD	*0.30*	*0.30*	*0.33*	*0.36*	*0.37*	*0.43*	*0.50*	*0.50*
CHEN								
AM	37.34	37.58	37.64	37.75	37.95	38.14	38.33	38.38
RQ	37.43	37.52	37.92	38.25	38.41	38.57	38.62	38.64
JD	37.22	37.28	37.59	37.86	38.13	38.38	38.67	38.70
AK	37.24	37.41	37.82	38.08	38.31	38.49	38.68	38.77
KR	37.24	37.32	37.57	37.79	38.03	38.27	38.48	38.55
MH	37.32	37.54	37.67	37.81	37.99	38.17	38.36	38.44
JF	37.28	37.73	37.62	37.71	37.94	38.16	38.37	38.40
TB	37.89	38.05	38.12	38.27	38.46	38.58	38.75	38.83
TA	37.48	37.65	37.9	38.17	38.44	38.72	39.01	39.14
Mean	37.38	37.56	37.76	37.97	38.18	38.39	38.59	38.65
SD	*0.21*	*0.23*	*0.19*	*0.23*	*0.22*	*0.21*	*0.22*	*0.24*

Post testing (Cont.)

Player	Sensation Pre 2min	Sensation 10min	Sensation 20min	Sensation 30min	Comfort Pre 2min	Comfort 10min	Comfort 20min	Comfort 30min	Mass Pre (kg)	Mass Post (kg)	Fluid intake (ml)	Sweat rate (L/hr)
BRIS												
TC	7.0	8.0	8.0	8.0	1.0	1.0	1.0	1.0	93.2	92.6	72	1.34
PG	7.0	8.5	9.0	10.0	1.0	1.5	2.0	3.0	86.8	86.3	284	1.57
TT	7.0	8.0	8.0	10.0	1.0	1.0	2.0	3.0	75.2	75.3	1018	1.84
CD	7.0	8.0	8.0	8.0	1.0	1.0	2.0	3.0	100.3	99.0	0	2.60
JF	7.0	9.0	10.0	11.0	1.0	2.0	3.0	4.0	83.5	83.0	392	1.78
Mean	7.0	8.3	8.6	9.4	1.0	1.3	2.0	2.8	87.80	87.24	353	1.83
SD	*0.0*	*0.4*	*0.9*	*1.3*	*0.0*	*0.4*	*0.7*	*1.1*	*9.53*	*9.06*	*404*	*0.48*
CHEN												
AM	7.0	8.0	8.0	9.0	1.0	1.0	1.0	2.0	83.2	82.0	0	2.40
RQ	6.0	7.5	8.0	8.5	1.0	1.0	2.0	2.0	91.8	91.6	286	0.97
JD	7.0	10.0	10.0	10.0	1.0	2.0	3.0	3.0	79.2	78.5	0	1.40
AK	6.0	8.0	8.0	9.0	1.0	1.0	1.5	1.5	89.4	89.2	300	1.00
KR	5.0	8.0	10.0	11.0	1.0	2.0	3.0	4.0	83.1	82.3	0	1.60
MH	7.0	9.0	9.0	10.0	1.0	1.0	2.0	2.0	84.0	83.2	90	1.78
JF	6.0	9.0	10.0	10.0	1.0	2.0	3.0	3.0	73.5	72.9	0	1.20
TB	8.0	10.0	10.0	11.0	1.0	1.0	2.0	2.0	89.7	88.9	82	1.76
TA	7.0	9.0	10.0	11.0	1.0	2.0	3.0	4.0	93.3	92.8	372	1.74
Mean	6.6	8.7	9.2	9.9	1.0	1.4	2.3	2.6	85.24	84.60	126	1.54
SD	*0.9*	*0.9*	*1.0*	*1.0*	*0.0*	*0.5*	*0.8*	*0.9*	*6.42*	*6.56*	*151*	*0.45*

Post testing (Cont.)

Player	Skin Temp Pre (°C)	Skin Temp 5min (°C)	Skin Temp 10min (°C)	Skin Temp 15min (°C)	Skin Temp 20min (°C)	Skin Temp 25min (°C)	Skin Temp 30min (°C)	Skin Temp Post 2min (°C)	Lactate Post 2min (mmol/L)
BRIS									
TC	30.9	32.5	33.4	33.8	34	34.3	34.5	33.5	1.6
PG	33.3	31.6	32.6	33	33.9	34.3	34.7	36.5	3.7
TT	30.8	30.4	31.7	32.4	31	30.6	32.1	33.6	1.3
CD	30.2	31.3	31.4	32.5	32.8	32.7	32.6	34.1	3.1
JF	32.1	31.8	33.4	34.2	33.6	33.4	34.3	36.1	2.1
Mean	31.5	31.5	32.5	33.2	33.1	33.1	33.6	34.8	2.4
SD	*1.2*	*0.8*	*0.9*	*0.8*	*1.2*	*1.5*	*1.2*	*1.4*	*1.0*
CHEN									
AM	31.1	32.6	33.9	33.8	33.8	34.2	33.7	36.9	2.3
RQ	31.8	32	34	34.8	35	34.9	35.1	36.8	1.8
JD	32.3	31.4	32.6	33.7	32.9	32.7	33.0	35.9	3.0
AK	32.6	31.6	33.1	33.2	32.3	32.1	32.5	34.3	2.1
KR	29.6	30.1	31.0	32.2	32.4	32.7	32.6	33.1	1.6
MH	29.4	32.0	33.3	34.0	33.5	33	32.9	33.6	2.0
JF	31.9	30.4	31.3	32.0	32.8	33.2	33.4	34.2	1.0
TB	32.6	32.3	33.8	34.5	34.1	34.1	34.6	36.7	0.9
TA	28.9	30.6	32	32.9	31.6	32.2	32.5	32.3	2.3
Mean	31.1	31.4	32.8	33.5	33.2	33.2	33.4	34.9	1.9
SD	*1.5*	*0.9*	*1.1*	*1.0*	*1.0*	*1.0*	*0.9*	*1.7*	*0.7*

Post testing – Repeated run-3 sprints

Player	Sprint 1 (s)	Sprint 2 (s)	Sprint 3 (s)	Sprint 4 (s)	Sprint 5 (s)	Sprint 6 (s)	HR 0s (bpm)	HR 30s (bpm)	HR 60s (bpm)	HR 90s (bpm)	HR 120s (bpm)
BRIS											
TC	10.17	10.25	10.83	10.78	10.90	11.00	163	161	143	133	127
PG	9.95	10.34	10.51	10.52	10.95	10.82	186	178	164	160	150
TT	10.22	10.72	11.27	11.35	11.11	11.14	190	186	170	149	139
CD	10.24	10.52	10.60	11.03	11.01	11.18	178	174	165	149	142
JF	10.16	10.20	10.85	10.97	11.26	11.20	192	186	174	159	152
Mean	10.15	10.41	10.81	10.93	11.05	11.07	182	177	163	150	142
SD	*0.12*	*0.21*	*0.29*	*0.31*	*0.14*	*0.16*	*12*	*10*	*12*	*11*	*10*
CHEN											
AM	10.01	10.2	10.48	10.46	10.8	10.72	170	164	147	130	114
RQ	10.08	10.57	10.74	10.97	10.93	10.88	176	171	154	138	125
JD	10.54	11.12	11.08	11.57	11.48	11.70	180	176	163	151	141
AK	10.61	10.99	11.33	11.44	11.61	11.53	175	166	152	146	135
KR	10.15	10.41	10.79	10.77	10.9	10.84	176	170	157	145	137
MH	10.33	10.64	10.84	10.99	11.05	10.92	168	151	133	127	118
JF	9.59	10.01	10.23	10.57	10.77	10.70	190	183	171	158	148
TB	10.55	10.99	11.15	11.52	11.24	11.36	183	164	150	139	126
TA	9.99	10.53	11.20	12.02	11.73	11.75	170	154	145	132	120
Mean	10.21	10.61	10.87	11.15	11.17	11.16	176	167	152	141	129
SD	*0.33*	*0.38*	*0.36*	*0.52*	*0.36*	*0.43*	*7*	*10*	*11*	*10*	*11*