AN INSIGHT INTO THE PROFILE CHARACTERISTICS AND TECHNICAL BATTING SKILL OF ADOLESCENT CRICKET PLAYERS

BY

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THESIS

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ABSTRACT

Background: Current traditional cricket practices incorporate the use of a netted-off pitch to provide cricket players the opportunity to hone their skills with bat and ball. The lack of ecological validity of these training environments results in the absence of important task and environmental constraints which influences the manner in which the sport is played. **Objectives:** The purpose of the current research was two-fold: firstly, it aimed to establish a profile database of adolescent cricket players in the Eastern Cape province of South Africa; and secondly, it aimed to investigate the efficacy of a constraints-led training intervention on skill development in adolescent cricket batsmen. **Methods:** Study I required 90 participants (u13: n = 40; u15: n = 50) to perform measures pertaining to anthropometric, morphological, flexibility and physical performance characteristics. This included stature, mass, body composition, limb length, flexibility, agility, and power measures. Study II was a case-control study (u15: n = 24), whereby the experimental group (n = 12) was exposed to a constraints-led batting protocol during the course of the cricket season. The objective of the protocol was to encourage the manipulation of the ball around the playing field. Pre- and post-intervention measures were performed using a batting skills test, which assessed batsmen’s capability to manipulate the ball to various areas of the playing field. **Results:** Study I revealed significant differences ($p < 0.0001$) in stature, mass, limb length and power variables when comparing the u15 age group with the u13 age group. No differences were recorded for agility. The u13 age group had greater linear correlations for the variables of interest compared to the u15 age group. Study II revealed no differences in technical skill between the experimental group and the control ($p < 0.315$). The tests also revealed that adolescent batsmen favoured hitting deliveries through the extra-cover scoring zone. The third-man and fine-leg scoring zones were least preferred to hit deliveries through. A number of limitations to the study design resulted in the inability to determine the efficacy of a constraints-led batting protocol on skill development in an adolescent batting cohort. **Conclusion:** The results of study I indicated that the onset of puberty played an important role in the measures and performances between the u13 and u15 age groups. The results of study II indicated that adolescent batsmen are not adept at manipulating the ball around the field. Recommendations are provided for both studies.

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CHAPTER I

INTRODUCTION

STUDY BACKGROUND

The increase in globalisation of interceptive sports, such as baseball, cricket, football, hockey, and tennis, has brought with it fundamental development in sports science, specifically the research of training procedures to maximise human performance. The growing financial investment within each of these sporting domains incentivises athletes to be at their peak, mentally and physically, to produce elite performance consistently (Johnstone, Mitchell, Hughes, Watson, Ford, & Garret, 2013). As such, researchers are constantly striving to identify various factors within human performance which, through development, could lead to overall improved performance.

One of the more complex interceptive sports is that of cricket. The fast-paced, high-intensity bat-and-ball sport has evolved significantly from the traditional social settings to an action-packed sporting experience (Noakes & Durandt, 2000; Woolmer & Noakes, 2008). The growth of cricket is reflective of the investments made within the sport, with an increasing number of countries (n = 106) adopting cricket as a common summer sport (International Cricket Council, 2015). Cricket is fast becoming one of the more lucrative team sports, and as such, competition amongst players is developing rapidly.

With the increase in competition, it is expected that cricketers are required to work even harder to breakthrough onto the professional roster. The common belief in the cricketing network is that if a potential cricketer has not broken through into the first class ranks before their early twenties, there is strong evidence to suggest it will never occur (Hinchliffe, 2011). As a consequence, cricketers that want to succeed at the highest level are required to have exceptional youth careers to stake a claim. For this to occur, cricketers require a strong foundation of development, most notably occurring at an adolescent level.

As cricket is a highly skill-based sport, training procedures and environments play a crucial role in the development of these skills. It is hypothesised that individuals who develop earlier, showing more ‘promise’ (whether it be size, skill, awareness, or so forth) at a young age, are afforded favourable extrinsic factors such as advanced training, state-of-the-art facilities, exposure and experiences that further influence the development of the individual (Barnsley & Thompson, 1988; Baker, Horton, Robertson-Wilson, & Wall, 2003; Tucker & Collins, 2012). Consequently, these individuals should develop exponentially faster than their age group competitors.

Intrinsic factors, such as anthropometric and morphological characteristics, may contribute to early success in skill-based sports, which could result in greater affordances to better training and facilities (Tucker & Collins, 2012). As such, a profiling database may be a useful tool to provide coaches with an early indicator as to the physical strengths and weaknesses of individuals, thus allowing those individuals to specialize within specific cricketing roles.

Study I: Profiling database

Very few profiling studies have been undertaken within a cricketing context, particularly at an adolescent level. The studies that have performed research on anthropometric, morphological and physical performance profiling have primarily focused on an elite, developed population (Stretch & Buys, 1991; Stretch, 2001; Pyne, Duthie, Saunders, Petersen, & Portus, 2006). The importance of this form of research should not be underestimated, as it could provide researchers with a comprehensive database for future reference with regards to talent identification and injury susceptibility.

Cricket is a team sport made up of eleven individuals with specific roles to perform. There are four primary disciplines within cricket, namely: bowling, batting, wicket-keeping and fielding. As fielding is performed by all players at some stage in the game, this should be considered a subsidiary discipline. Within each discipline, individuals may differ in technique and execution. For example, some bowlers may rely on pace and bounce to effect wickets, whereas others make use of swing and seam. Furthermore, spin bowlers rely on spin and variation of pace to deceive batsmen. Some individuals are equally adept at bowling and batting, and are referred to as all-rounders. Previous literature has determined that the anthropometric, morphological and physical characteristics of individuals differ across roles within the team (Stretch & Buys, 1991; Christie, 2008; Dana, Webster, & Travill, 2014).

Anthropometric and morphological variables often attract individuals to specific roles early in their cricket careers, favouring a specific discipline above others (Stretch, Bartlett, & Davids, 2000). For example, it has been established that taller cricketers with longer limb lengths are predisposed to generate faster bowling speeds, and are thus encouraged to pursue the fast bowling discipline (see Pyne *et al*., 2006; Stuelcken, Pyne, & Sinclair, 2007). With this in mind, establishing a database of adolescent anthropometric, morphological and physical characteristics may provide future researchers and practitioners with a reference for suggesting individuals to specific cricketing roles as well as providing details for retrospective talent identification.

Study II: Current adolescent training procedures

It is understandable that international training procedures are mimicked at the lower levels of cricket coaching. Although these sub-elite levels may not have the resources to fully incorporate international training procedures, the basic framework of training is still being utilized (Stretch, McKellar, & Nurick, 1998a).

Current adolescent training procedures focus intently on the use of net practices to train the technical skill of adolescent bowlers and batsmen. The net practice is the cornerstone of traditional skill-based training in cricket, with batsmen and bowlers honing their skill within the confinements of a netted-off pitch (Stretch *et al.*, 1998a). This allows bowlers to experiment with different delivery types without being hit to the furthest corners of the playing field, as well as affording batsmen the opportunity to practice different cricket strokes for different types of deliveries.

Depending on resources available, some adolescent cricket teams may train with the use of a centre-wicket. This allows for a greater representation of task constraints, affording batsmen and bowlers key environmental cues to assist with skill training (Renshaw, Chappell, Fitzgerald, Davison, & McFadyen, 2010a; Vickery, Dascombe, Duffield, Kellett, & Portus, 2013). However, the majority of adolescent training procedures make use of net practices due to the efficiency of man-management, with minimal effort for preparation.

As cricket is a highly skilled interceptive sport, technical capability plays an influential role in an individual's success. Skill acquisition is a commonly researched domain, with researchers keenly attempting to identify the major information-processing functions of motor learning (see McMorris, 2004). Theories of motor learning are often implemented within interceptive sports research in an attempt to substantiate the support of these theories.

One of the trends in interceptive sports training has been the use of the constraints-led approach to training skilled performance (see Chapter II: Part II). Constraints-led training promotes the manipulation of specific constraints within a training procedure to simplify the learning process, and/or provide the participants with a greater affordance to practice (Caserta, Young, & Janelle, 2007; Fajen, Riley, & Turvey, 2009; Renshaw & Holder, 2009).

For example, a cricket coach may want bowlers to practice 'yorker-length' bowling and batsmen to improve their reaction times. The coach may manipulate the length of the cricket pitch which would provide different affordances for bowlers and batsmen. For bowlers, lengthening the pitch would force the bowlers to bowl fuller lengths, which would translate to a 'yorker-length' when returning to an original-length pitch. For batsmen, shortening the pitch would afford batsmen less decision-making time, forcing them to react faster to each delivery. When transferring back to an original-length pitch, these batsmen would have the perception of having more time to decide on an appropriate cricket stroke. Although the quantity of training would not change, implementing a constraints-led approach would increase the quality of training, thus improving the efficiency of the training session.

The constraints-led approach to training is based on the theory of the ecological dynamics approach to motor learning, arguing that learning is influenced by interacting constraints of the task, the environment, and the individual (Renshaw, Oldham, Davids, & Golds, 2007; Renshaw, Chow, Davids, & Hammond, 2010; Davids, Araújo, Vilar, Renshaw, & Pinder, 2013). The ecological dynamics approach advocates the implementation of a representative learning environment. This design ensures that training procedures maintain a strong functional coupling and high action fidelity to afford participants representative constraints during training sessions (Pinder, Davids, & Renshaw, 2011).

Results from research adopting the constraints-led approach have shown some support for the use of this approach to assist with the development of technical skill of participants (see Chapter II: Part II). However, there is need for further research within this topic to provide more clarity.

Although cricket research has recently adopted training designs representing the playing conditions of real match situations (Renshaw *et al.*, 2010a; Vickery, Dascombe, & Duffield, 2014), there is a lack of research on the practical implication of a representative training design to enhance technical skill of cricket batsmen. This research has primarily focused on the physiological benefits of representative training designs, overlooking the benefits which may be seen from a technical aspect. Therefore, researchers and practitioners should focus on implementing representative practice environments whereby batsmen can train under similar circumstances seen in real match situations. Having a representation of real match situations, cricketers will be afforded the opportunity to train under holistic task and environmental cues, thus improving the overall quality of the training session.

STATEMENT OF THE PROBLEM

Study I

It has been established at a tertiary and professional level that anthropometric and morphological differences occur between cricketing roles; however, no profiling has been performed on a younger, developing population. At an adolescent level, individuals have not fully developed and as such, discrepancies between each discipline may not be as apparent. Due to the lack of profiling at an adolescent level, there is a call for research within this domain to establish a database for future adolescent cricket research.

Study II

The current trend in skill acquisition research is the use of representative training designs to improve the fidelity of training sessions, with greater similarity to real match situations (Renshaw & Holder, 2009; Pinder *et al.*, 2011). Improving the design of training sessions is believed to improve the specificity, and thus reduce the transfer effects resulting from the interchange between training sessions and real match situations (Reilly, Morris & Whyte, 2009). With improved training designs, practitioners and researchers experiment with altering specific constraints of game play in an attempt to improve skilled performance. This constraint manipulation is believed to alter the dynamics of training sessions, therefore requiring individuals to constantly reorganize their technical systems.

The lack of a representative design in the traditional net practice fails to encourage batsmen to train the ability to manipulate the ball according to the field settings. Instead, batsmen focus on hitting 'textbook' strokes out of the centre of the bat, without being dismissed. Consequently, the most important part of batting, scoring of runs, is often neglected as there is no environment created to encourage batsmen to manipulate the ball around the field. Increasing the representativeness of real match batting into a practice environment, such as the constraint of fielders (or at least possible fielding positions), may provide batsmen with added benefits when transitioning from training to real match situations.

The lack of alternate, skill-based training sessions to assist cricket batsmen warrants the inquisition of a constraints-led training program to determine if skilled performance can be trained by more efficient means than traditional cricket training. Introducing the environmental cues of field placings and/or fielders may produce a training environment of a better quality than the traditional net practices. Having a more match-specific outcome, such as manipulating the ball around the playing surface, may result in improved quality of training sessions, thus improving batting performance.

PURPOSE OF THESIS

Study I

The primary aim of this study was to derive a database of anthropometric, morphological and physical characteristics for adolescent cricket players (u13 and u15 age groups). A subsidiary aim of this study was to assess correlations between anthropometric, morphological, flexibility, and physical performance data according to specific roles in the cricket team, as well as any month of birth effects.

Study II

The primary aim of this study was to determine whether an intervention of a constraints-led batting protocol could assist the development of technical skill[1] of batsmen, resulting in improved performance during a batting skills test. The intervention protocol would manipulate the environmental constraint of field placing, resulting in a change in gaps around the field, to provide participants with the opportunity to manoeuvre the ball around the playing surface. A subsidiary aim of this study was to assess adolescent batsmen's strengths and weaknesses of scoring areas, as well as identifying favoured scoring areas.

DELIMITATIONS OF STUDY I

Sex restrictions of the participants

The study focused on the profiling of male adolescent cricket players, therefore the results of the study should only be applied to this cohort. Further research would be needed to assess profiling differences in female adolescent cricket players in South Africa.

Sample representation

The sample represents adolescent cricket players in the Eastern Cape province of South Africa. The results from this database should not be used to infer profiling differences for samples in other sporting domains, such as rugby or football. Differences in anthropometric, morphological and physical performance parameters may be noted.

DELIMITATIONS OF STUDY II

Sex restrictions of the participants

As adolescent cricket in South Africa is male-dominated, the study focused on training male adolescent cricketers to allow for a larger sample size. Therefore, the results from this study should only apply to male adolescent cricketers and not female adolescent cricketers.

Sample representation

[1] Technical skill, for the purpose of this study, refers to a batsman's capability to manipulate the ball to a desired area in the field of play.

Top-order batsmen (first six batsmen in the batting order) were used to eliminate possible discrepancies from variation of skill levels. As such, the results of this study should only be applied to top-order batsmen and not all cricketers alike. The effects of the constraints-led training protocol on batsmen of a lower skill level (i.e. bowlers) should not be inferred from the results of this study.

Functional coupling

To control for the variation from delivery to delivery of live bowlers, the study design incorporated the use of a ball projection machine to afford each participant an equal opportunity to perform the pre- and post-intervention testing protocol. The use of a ball projection machine reduced the variation of deliveries, with line and length controlled for under each batting condition. However, the perception-action coupling of batting was also compromised to ensure scientific rigour.

CHAPTER II

REVIEW OF LITERATURE

The *Review of Literature* chapter has been separated into two parts: Part I is presented as a narrative review, while Part II is presented as a systematic review.

PART I: NARRATIVE REVIEW

Past and future of cricket research

Ecological dynamics approach

Skill acquisition

PART II: SYSTEMATIC REVIEW

The effectiveness of constraints-led training on skill development in interceptive sports: a systematic review

The reason for this was that the systematic review would provide clarity on the effectiveness of constraints-led training within interceptive sports through the systematic analysis of evidence from previously related epidemiological studies. From this evidence, the author would be able to identify whether there would be merit in pursuing an intervention study with the use of the constraints-led approach to training. However, in order to understand the concept of constraints-led training, it is important to discuss the theoretical background of the approach, which would be best presented as a narrative review.

PART I: NARRATIVE REVIEW

PAST AND FUTURE OF CRICKET RESEARCH

Cricket research has seen substantial growth over the past few decades as a consequence of an increase in popularity of the sport. The majority of growth has derived from the physical demands of cricket play (Christie, Todd & King, 2008; Christie, 2008; Duffield, Carney & Karppinen, 2009; Petersen, Pyne, Dawson, Portus & Kellett, 2010; Houghton, Dawson, Rubenson & Tobin, 2011), the biomechanical processes of batting and bowling (Elliot, Foster & Gray, 1986; Hurrion, Dyson & Hale, 2000; Elliott, Wallis, Sakurai, Lloyd & Besier, 2002; Ranson, Burnett, King, Patel & O'Sullivan, 2008), and the injury occurrence within the sport (Elliot, 2000; Dennis, Farhart, Goumas & Orchard, 2003; Orchard, James & Portus, 2006; Saw, Dennis, Bentley & Farhart, 2009).

In contrast, very limited research has been performed on the anthropometric and morphological profiling of cricket players (Stretch & Buys, 1991; Pyne *et al*., 2006; Dana *et al*., 2014) and the skill acquisition in batting through various cricket training procedures (Stretch, Nurick, & McKellar, 1998b). Due to the vast and complex nature of the sport, there are still many facets of the game that require extensive research to supplement the current literature. This section provides a concise summary of the research exploring anthropometric and morphological profiling of cricket players, biomechanical understandings of cricket technique, physical demands of cricket gameplay, and the skill acquisition of batting.

Cricket profiling research

The cricket team is divided into different roles performed by each player. Each of these roles has with it different physical requirements, which has resulted in differences to anthropometric, morphological and physical characteristics between players (Pyne *et al.*, 2006; Christie, 2008). These differences in physical requirements ‘attract’ certain advantageous anthropometric and morphological characteristics (Stretch *et al.*, 2000). Most notably, cricketers are categorized as follows: batsmen, bowlers, and wicket-keepers. Batsmen and bowlers are also categorized as fielders when not performing their primary role. Fielding, however, should be considered a subsidiary role as individuals are first selected for a team based on their capability with bat or ball. All-rounders are referred to individuals who are equally adept at batting and bowling, and perform both these roles during a match.

Of the few studies on cricket profiling, the majority focused on university and professional cricketers, who have fully developed, physically and technically, within their specific roles in the cricket team (Stretch & Buys, 1991; Johnstone & Ford, 2010; Koley, Kumaar, & Shadagopan, 2012; Dana *et al.,* 2014; Kumar & Gladykirubakar, 2014). Results from these studies have revealed discrepancies in physical appearance between different roles within the team. The most commonly reported discrepancy occurs between fast and spin bowlers (Dana *et al.,* 2014; Kumar & Gladykirubakar, 2014). Fast bowlers are reported to have a taller stature with longer arm and leg lengths (Choudhary*,* Tiwari, Kumar, & Rai, 2012; Dana *et al.,* 2014; Kumar & Gladykirubakar, 2014). The most common discrepancy reported in variables between batsmen and bowlers also pertains to stature, with the bowler tending to be of a taller stature (Stretch & Buys, 1991; Dana *et al.,* 2014). Batsmen, on average, are shorter and heavier (relative fat mass) than bowlers (Stretch & Buys, 1991). No differences have been recorded in the physical performance measures between batsmen and bowlers (Dana *et al.,* 2014).

To the author's knowledge, only one study has incorporated adolescent cricketers with a comparison to elite, adult cricketers. This study focused on the anthropometric and physical differences between senior and junior fast bowlers (Pyne *et al*., 2006). Senior bowlers had significantly greater values for stature and mass, with greater lengths and breaths of both upper- and lower-body regions (Pyne *et al.*, 2006). Senior bowlers also showed substantially greater upper- and lower-body strength measures, which ultimately resulted in greater peak bowling velocity. The authors noted that the predictor variables of static jump, bench throw, counter-movement jump (CMJ), and body mass were strongly correlated with peak bowling speed for junior bowlers (Pyne *et al.*, 2006). However, the predictor variables for senior bowlers that were strongly correlated with peak bowling velocity were the deltoid throw, static jump, CMJ, arm length, and anterior-posterior chest depth (Pyne *et al.*, 2006). No other studies have focused on the anthropometric, morphological and physical performance profiling of adolescent cricketers. There is also a lack of research on cricket batsmen and wicket-keepers.

The anthropometric and physical performance measurements of adolescent cricketers would provide interesting results for interpretation as individuals have not fully developed. Establishing a database of adolescent cricketer profiles may provide early indicators of possible specialist roles within a team for future anthropometric researchers. Comparing adolescent variables with a mature population may provide context for researchers and practitioners, such as strength and conditioning coaches, to advise specific training programs and possible role changes suited to each individual's unique anatomical setup.

Cricket Profiling Measurements

The variables recorded within each anthropometric profiling study overlap, with the limb length, stature, mass, body mass index (BMI), seven-site skinfolds, hip and waist circumference, and somatotype being popular anthropometric variables used to assess cricket players (Stretch & Buys, 1991; Stuelcken *et al*., 2007; Koley *et al.,* 2012; Dana *et al*., 2014). Muscular strength variables include one repetition maximum (1-RM) tests for various muscle groups, most commonly: chest, hamstring, quadriceps, bicep and shoulder. Muscle endurance measures include maximal repetitions of push ups, crunches, and pull ups (usually limited to one minute) (Koley *et al.*, 2012; Dana *et al*., 2014). Physical performance measures include short distance sprint time (up to 40 metres), repeated sprint tests, agility tests and reaction time tests (Koley *et al*., 2012; Dana *et al.*, 2014). Flexibility measures include (and are not limited to) trunk extension, hamstring (sit and reach), and shoulder flexion and extension tests. Combinations of these variables may provide researchers with a holistic description of the anthropometric, morphological and physical performance characteristics of cricket players.

Biomechanical research

Biomechanical studies of cricket gameplay has allowed researchers to identify, through kinematic analyses, the structural limitations of movements during cricket play and the risk factors associated with transgressing these thresholds (Elliot *et al*., 1986; Hurrion *et al*., 2000; Elliott *et al*., 2002; Ranson *et al.,* 2008; Penn & Spratford, 2012).

Practitioners have traditionally taught batting and bowling technique according to templates of former 'great' international cricketers (Bradman, 1958; Australian Cricket Board, 2001; Woolmer & Noakes, 2008). Biomechanical research has been used to support the 'correct' movements of batsmen for various types of cricket strokes, as well as bowlers with regards to legal bowling actions (Glazier, Davids, & Bartlett, 2000; Stuelcken, Portus, & Mason, 2005; Portus & Farrow, 2011; Penn & Spratford, 2012).

For cricket batting, the production of a cricket stroke has a number of smaller steps to create the whole stroke (Stuelcken *et al*., 2005). These steps include: the stance and initial movement, the back-lift, the forward stride, the downswing, the bat-ball impact, and the follow-through (Stuelcken *et al.* 2005). Biomechanical research has observed and recorded the techniques adopted by skilled batsmen and compared these to the techniques adopted by less-skilled batsmen to assess where differences may occur (Stuelcken *et al*., 2005; Taliep, Galal, & Vaughan, 2007; Penn & Spratford, 2012). These observations have then been cross-referenced with coaching manuals to provide support for specific movement patterns in cricket batting (Penn & Spratford, 2012).

The studies have been able to identify traits of movement techniques which are better suited for a more consistent outcome; however they do not endorse a one-fits-all rule such as a 'perfect' technique (Penn & Spratford, 2012). However, practitioners are often blinded by the idea that the 'perfect' technique of batting or bowling would provide the best offence or defence to opposition players. This may be due to a lack of a holistic understanding of performance within cricket gameplay or a misunderstanding of individualisation (to be discussed in the *Skill Acquisition* section to follow).

For a detailed review of the research on the biomechanics of cricket play, see Stretch *et al.*, (2000), Stuelcken *et al*. (2005), Taliep *et al*. (2007); Weissensteiner, Abernethy, Farrow, and Müller (2008), Portus and Farrow (2011), and Penn and Spratford (2012).

The combination of research on the physical demands and biomechanics of cricket play has provided researchers with an understanding of the incidence and cause of injury within the sport. This includes the structurally weak anatomical areas for bowlers and batsmen alike. The most commonly affected area for fast bowlers is the lower back (Gray, Derman, & Vaughan, 2000; Orchard, James, Kountouris, Portus, 2010), and the most commonly affected area for batsmen is the biceps femoris (Christie & Shepard, 2013; Pote & Christie, 2014). It is understood that the severe lumbo-pelvic movements and ground interaction of fast bowling are responsible for repeated stress on the lower back of bowlers (Gray *et al*., 2000; Olivier *et al*., 2015); whereas the repeated eccentric contractions while running between the wickets is responsible for the fatigue of the biceps femoris muscle (Christie & Shepard, 2013; Pote & Christie, 2014).

Physiological research

Literature on the physiological demands of cricket gameplay has developed significantly with researchers exploring the aetiology of musculoskeletal damage and the energy costs associated with various stages of cricket play (Elliot, 2000; Christie, 2008; Christie *et al*., 2008; Duffield *et al*., 2009; Nicholson, Cooke, O'Hara, & Schonfeld, 2009; Petersen *et al*., 2010; Houghton *et al*., 2011; Pote & Christie, 2014).

Initial reports on the physiological demands stated that cricket was a low-intensity sport, with little requirement for elite athletic capability (Noakes & Durandt, 2000; Christie, 2008). Through the use of indirect calorimetry, Fletcher (1955) concluded that the energy expenditure for an average test match player was 86.4 $kcal.m^2.h^{-1}$ (Fletcher, 1955). This equated to an intensity marginally higher than was required to stand (Christie, 2008). Furthermore, research focussing on the heart rate of batsmen during one-day international (ODI) matches found that heart rate rarely exceeded 128 $bt.min^{-1}$ (Gore, Bourdon, Woolford, & Pederson, 1993).

However, with the advancement of testing equipment and procedures, researchers have been able to determine a more precise understanding of the physical demands. Christie (2008) found that a seven-over batting drill resulted in a mean energy cost of 301 $kcal.m^2.h^{-1}$, significantly higher than previously thought. A mean heart rate of 152 $bt.min^{-1}$ was recorded during this batting protocol, contradicting the research established by Gore *et al.* (Christie, 2008). Pote and Christie (2014) found that the mean heart rate for a self-selected pace during the BATEX protocol was 135 bt.min^{-1}, with mean heart rate rising to 152 bt.min^{-1} during maximal sprint performances. The BATEX protocol requires participants to face thirty overs of bowling from a ball projection machine, with the object to score one hundred runs (Houghton *et al.,* 2011). These one hundred runs are broken down into singles, two's, three's and four's, with batsmen required to run a set number of runs each over. The protocol is divided into six stages of five-over spells, with alternative stages requiring differing levels of intensity (Houghton *et al*., 2011). Stages one, three and five are designated as self-selected sprinting stages, while stages two, four and six are designated as maximal sprint stages (Houghton *et al*., 2011). As the stages suggest, the odd stages are performed at a pace selected by the participant, whereas the even stages are performed at a maximal sprint effort. The outcomes of these high-intensity batting protocols suggest that cricket gameplay, specifically batting, is performed at a much greater level of intensity than previously suggested.

With the relatively recent introduction of new, shorter formats of the game, the number and the intensity of cricket matches has increased (Vickery *et al.*, 2014). Earlier research on the physiological demands of cricket may no longer be relevant due to the restructuring of the sport, such as changes to the laws of the game. These changes in cricket gameplay warrant a call to evolve testing procedures to ensure that ecologically valid measures are utilized to provide further understanding of the physiological demands of cricketers. This would provide practitioners with current knowledge to enforce proper precaution to ensure longevity of cricketers. The physiological elements of cricket can be a major performance limiting factor that may affect cricketers of all skill-levels; therefore attention to this domain of research is highly warranted.

A full summary of the physiological research in cricket is over and above the purposes of this research study. For a better understanding of the physical demands of bowling and batting see the work of Stretch *et al*. (2000), Noakes and Durandt (2000), Christie (2008), and Pote and Christie (2014).

Skill acquisition research

The technical skill of batting is the focal point of this section and shall be discussed in detail to follow. As a consequence, the technical skill of bowling will be overlooked.

Batting is a highly complex interceptive action requiring an intricate combination of mental, perceptual, physical, technical and tactical skills in order to perform successfully (Weissensteiner *et al.*, 2008). Due to the physical and temporal constraints of the sport, elite batsmen are required to have exemplary perception-action and decision-making skills to ensure that each delivery is matched with an *appropriate stroke*[2] (see Abernethy, 1981; Land & McLeod, 2000; Stretch *et al*., 2000). The ability to perceive, decide and produce an appropriate action response is complicated by the interacting constraints of the individual, the task and the environment (see Renshaw, Davids, & Savelsbergh, 2010). Batsmen also have the option to leave a delivery that does not threaten to hit their wickets, thus forcing bowlers to deliver the ball closer to batsmen (or to the wickets), thereby reducing the risk of certain cricket strokes.

Task constraints include the physical, spatial and temporal constraints of batting, defined by the size of the bat and ball, the speed, line and length of the delivery, as well as any ball deviations after delivery release (i.e. swing, seam and spin) (Stretch *et al*., 1998b). Consequently, batsmen may be required to decide and execute appropriate cricket strokes within a matter of milliseconds, depending on the speed of the bowler (see Glencross & Cibich, 1977; Abernethy, 1981; Land & McLeod, 2000).

Further task constraints include the size of the playing field and rules of the sport, such as current batting scenarios and opposition field placements. Depending on the match situation, batsmen may be required to play a variety of attacking or defensive strokes to achieve the specific goals of the scenario. The constraint of opposition fielders influences the manner in which batsmen hit the ball, whether aerial or along the ground, and the placement of specific cricket strokes. Additional difficulty is provided as batsmen are expected to manipulate as many deliveries as possible

[2] The term appropriate stroke is used as a batsman may be able to produce a variety of cricket strokes for any particular delivery; however, the selection of an incorrect (or inappropriate) stroke may result in dismissal, therefore terminating the batsman's innings.

around the playing field, avoiding opposition fielders, in order to accumulate runs within a set amount of deliveries (Vickery *et al.*, 2014). The interceptive-manipulative manner of batting is anatomically unnatural and requires extensive training to learn and develop (Woolmer & Noakes, 2008).

In order for successful performance, regardless of the sport, it is critical to ensure that development of motor skills is achieved by means of effective training (Müller & Rosalie, 2010). Training plays an essential role in the growth and improvement of an individual's skill, as well as the refinement of specific techniques. Training within cricket incorporates a combination of different factors, including physiological (strength and conditioning), tactical (situational awareness and decision-making) and technical (technique and execution) skill development. As this study focuses on the training of technical skill of cricket batsmen, the other factors shall be omitted.

The fundamental basis of traditional cricket training requires batsmen and bowlers to refine their skills and techniques within the confinements of a netted-off pitch (Stretch *et al*., 1998a, Renshaw & Holder, 2009). This form of training ('net practice') affords bowlers the opportunity to work on specific deliveries and areas suited for real match situations, as well as allowing batsmen to work on appropriate cricket strokes for specific types of delivery.

Cricket nets were designed to produce effective and efficient training for both batsmen and bowlers, nullifying the need for fielders. Due to the netted-off pitch, wayward deliveries and well-struck strokes would not travel too far from the practice area, with bowlers and batsmen easily retrieving deliveries in an attempt to save time and effort. Unfortunately, the 'net practice' has not altered substantially over the years and is seen as the basic preparation for all cricketers (Stretch *et al*., 1998a, Renshaw & Holder, 2009). Although science and research within the sport has seen significant advancement, the filtration through to the design of the ubiquitous net practice has failed to occur.

Variations to net practices include the use of ball projection machines or 'throw downs' (a player throws balls to a batsman) in replace of a live bowler to enable batsmen to train more specific cricket strokes. This is often used as it allows the batsman to control the line and length of the delivery, thereby allowing specific strokes to be trained more efficiently (i.e. cover drive/ on-drive/ cut/ pull).

Traditional cricket training has both strengths and limitations in design: the advantage for using such a practice structure is that the net stops the ball from traveling far distances from the practice area. This allows practices to run efficiently with minimal delays between deliveries. Net practices, with the use of live bowlers, maintain a strong perception-action coupling between batsman and bowler, as would be the case in real match situations. Furthermore, net practices require little maintenance and preparation as the surface used is often concrete, resulting in a more economical option for many coaching institutions. However, the net practice has a number of limitations with regards to structure and goal-oriented outcomes (Woolmer & Noakes, 2008; Renshaw & Holder, 2009).

Net practices have a strong focus on the development of individual techniques, undermining the importance of training the execution of cricket strokes, which are essential for elite performance (Renshaw & Holder, 2009). Developing individual techniques is an important facet of the sport as it provides batsmen with a structured 'template' in which to face deliveries of a greater difficulty (Woolmer & Noakes, 2008). However, equally important is the ability to utilise those learned skills and techniques in an optimal, functional manner in order to achieve maximum performance.

The fundamental pitfall of net practice is that it fails to take into consideration a holistic approach to training cricketers. Cricket practices have primarily focused on the interaction between batsmen and bowlers, failing to acknowledge the constraining effect that opposition fielders have on game tactics, decision-making and execution of cricket strokes. As a result, batsmen are training without the environmental cues of fielders or field placements, which should be considered significant task constraints and would undoubtedly have an effect on the decision and execution of cricket strokes. Simply put, batsmen are being taught the correct technique on how to play a cover drive, without any consideration of a possible fielder blocking off that particular gap in the field.

Two main consequences arise from net practice: (*i*) batsmen tend to play an array of attacking strokes with the knowledge that they cannot be dismissed, and (*ii*) batsmen are lured into believing that they are batting well due to good ball-striking, as well as the execution of 'textbook' cricket strokes. Consequently, batsmen leave net practices under false pretences that they are 'in form' or 'hitting the ball well', but in reality these batsmen do not have the knowledge of whether they would have hit any number of balls straight to opposition fielders, or whether those cricket strokes would have produced any runs at all. Therefore, when transitioning to real match situations, these same batsmen (who have been batting 'expertly' in the nets) may struggle to score runs because many of their strokes are being hit straight to fielders. In other words, net practice lacks the game-specific intensity and constraints, as well as the lack of outcomes-based focus (such as runs scored) that would be seen in real match situations (Vickery *et al.*, 2014).

With that said, cricket practices may also take the form of centre-wicket sessions. Depending on resources available, cricket teams may train on an actual playing field (centre-wicket practice) whereby skills learned or improved in the nets may be tested in a better represented setting (i.e. similar to real match situations). Centre-wicket practices are not as common as net practices and are usually only available to teams of a higher skill level (or with greater resources). Net practices, however, make up the majority of cricket training across all teams, irrespective of skill level, as they are easier to manage from a coaching perspective, as well as more efficient in terms of player involvement (i.e. everyone has something to do).

Currently, research on the practice setup and training procedures of cricket players has been poorly assessed. To date, there have been a handful of studies exploring the nuances of skilled batting performance (Stretch *et al*., 1998b; Weissensteiner *et al*., 2008; Portus, Timms, Spratford, Morrison, & Crowther, 2010; Weissensteiner, Abernethey, & Farrow, 2011). These have varied from constraints-led training of cricket batsmen to the information-processing of skilled versus unskilled batsmen. The only intervention training protocol that focused on skill acquisition was that of a study by Stretch *et al*. (1998b). The authors designed a study method whereby participants of different skill levels trained with the use of a narrow cricket bat. The theory behind the design was that the narrow bat would force participants to hit the ball out of the centre of the bat, therefore decreasing mishits and misses (Stretch *et al*., 1998b). The result from this study showed that skilled batsmen did not benefit from the use of a narrow bat, but unskilled batsmen improved their performance significantly (Stretch *et al.* 1998b). The researchers concluded that this form of training should be implemented to assist the development of unskilled batsmen.

The latest trend in cricket research has been the use of a centre-wicket protocol, termed BATTLEZONE, which enables researchers and practitioners to simulate real match situations within a training environment (Renshaw *et al*., 2010; Vickery *et al.*, 2014). The BATTLEZONE is a training environment which makes use of a circular net, one metre in height, enclosing the 30-yard circle around the pitch (Renshaw *et al*., 2010). The design of this protocol promotes an intensified training scenario within the inner ring (see Renshaw *et al*., 2010; Vickery *et al.*, 2014). Within this design, batsmen train against live bowlers, with live or mock fielders in place to provide holistic environmental cues (Renshaw *et al*., 2010). As a result, batsmen are made aware of where specific cricket strokes are being placed and the resultant runs rewarded for each stroke. This training design also provides cricketers with a high-intensity exercise bout, which mimics the physical demands of real match situations (Vickery *et al.*, 2014).

However, research on the BATTLEZONE has focused primarily on the ecological validity of the training exercise, with regards to the physiological demands of real match situations (Renshaw *et al*., 2010; Vickery *et al.*, 2014). These studies have demonstrated that the BATTLEZONE protocol is reflective of the physiological demands over and above that of real match situations (Renshaw *et al*., 2010; Vickery *et al.*, 2014). In other words, the physiological demands of training within the BATTLEZONE protocol are at a greater intensity than the demands recorded in real match situations, for specific positions within the inner ring. The exception may be for boundary fielders, often fast bowlers that are resting between overs, who have a reduced workload as the need for boundary fielding has been removed. Thus boundary fielders would have a lesser intensity compared with the inner ring fielders (Vickery *et al*., 2014).

The technical aspect of this form of training has not been adequately studied, with the only research performed by Vickery *et al*. (2014). The authors looked at the technical demands of the BATTLEZONE in relation to real match situations to support ecological validity (Vickery *et al.*, 2014). Yet the technical demands of batting were defined according to the number of balls faced, the number of balls hit, and the percentage of good contact shots (Vickery *et al.*, 2014). The author found that the demands of the BATTLEZONE were representative of the demands of real match situations (Vickery *et al.*, 2014).

However, there was no evaluation of stroke accuracy within the field of play, or the ability to manipulate the ball around the playing surface. This is an important attribute of cricket batsmen, as it has been established that skilled cricket batsmen have a greater capability to manipulate the ball around the playing field, therefore scoring a greater number of runs than unskilled batsmen (Portus *et al*., 2010; Weissensteiner *et al.*, 2011).

In an attempt to identify discrepancies between skilled and less-skilled batsmen to manipulate the ball around the playing field, a novel study exploring the validity of a batting skills test to identify skilled batsmen was designed by Portus *et al.* (2010).The authors discovered that batsmen of a greater skill level had a higher success with the batting skills test compared with their lesser-skilled counterparts (Portus *et al*., 2010).

The objective of the batting skills test required batsmen to manipulate a series of deliveries from a ball projection machine, varying in speed and length, to as many target zones around the playing field, in a regulated sequence (Portus *et al.,* 2010). Of the three different skilled groups, the ‘Elite’ batsmen (mean age 31 ± 3 years) outperformed the ‘Emerging’ batsmen (mean age 22 ± 3), who in turn outperformed the ‘Junior’ batsmen (mean age 18 ± 1) in terms of runs scored (Portus *et al*., 2010). The authors concluded that the batting skills test aptly tested batsmen’s capability to manipulate a variety of deliveries to different areas of the playing field.

The lack of attention to outcomes-based research, namely the performance of batsmen with regards to runs scored, warrants the need for further research within this skill acquisition domain. The validation of the batting skills test should provide future researchers with an evaluation tool to help establish a difference in skilled performance between cricket batsmen, allowing researchers to develop training protocols to help assist with the development of skilled batting performance.

ECOLOGICAL DYNAMICS APPROACH

Initial reviews of the relevant peer-reviewed journal articles indicated that the constraints-led approach to motor learning and training is based on the theoretical framework of the ecological dynamics approach (see Renshaw *et al.*, 2007;

Renshaw *et al.*, 2010; Davids *et al.*, 2013b). This section serves to provide a brief introduction to the ideologies of this approach.

The ecological dynamics approach is a psychological theory of motor learning that emphasises the importance of the individual within the context of the performance environment (see Gibson, 1979; Araújo, Davids, & Hristovski, 2006; Renshaw, Davids, Shuttleworth, & Chow, 2009; Davids *et al*., 2013b; Greenwood, 2014). The model suggests that motor learning occurs as a result of the interaction between informational affordances provided from the environment and action responses of the individual (Stretch *et al.*, 2000).

Whereas traditional cognitivist theories of motor learning, such as Fitts and Posner's *Three Stage Theory*; Gentile's *Model of Learning*; Adam's C*losed-looped Theory of Learning*; Schmidt's *Schema Theory*; and the *Observational Learning Theory* (see McMorris, 2004 for a full review), focus solely on either the individual or the environment in question, the ecological dynamics approach highlights the mutuality of the relationship between these two factors (Araújo *et al*., 2006).

Although the aforementioned cognitivist theories may differ from model to model, the general structure of the internal processes of learning remains similar: (*i*) perception of stimuli, (*ii*) recognition and/or memory recall, and (*iii*) appropriate action response (see McMorris, 2004). These models tend to exaggerate their interpretation of information with internalized models of the world (Stretch *et al*., 2000). In other words, these theories overemphasise the importance of having a structured informational template to recall upon (memory).

Conversely, the ecological dynamics approach acknowledges the importance of environmental affordances which influence decision-making and response outcomes (Stretch *et al.*, 2000). These information affordances vary from task to task, and shape the way an individual responds.

This approach to motor learning is derived from concepts of ecological psychology and dynamical systems theory, whereby individuals are viewed as complex, nonlinear, neurobiological systems that act in accordance with unstable environments to produce appropriate movement patterns for a given task objective (Davids & Baker, 2007; Renshaw *et al*., 2009; Davids *et al*., 2013b).

Ecological psychology

Applied from ecological psychology is the understanding that unstable environments provide individuals with specific 'affordances' (*def.* opportunities for action) that influence the outcome of the action (Fajen *et al.*, 2009: 79). Ecological psychologists propose that behaviour is regulated by the interacting relationship between the individual and the environment (Greenwood, 2014). The proposition is that behaviour is controlled by the coupling between an individual's action and the dynamic environmental information that is presented (Gibson, 1979).

One of the key objectives of ecological psychology is to understand the interaction of perception and action by means of analysis of the information available in task-specific situations (Kelso, 1995; Beek, Jacobs, Daffertshofer, & Huys, 2003). This includes the investigation of how perceptual information shapes action in dynamic environments, and how those actions create more information to support an individual's behaviour (Kelso, 1995; Beek *et al.,* 2003).

Dynamical systems theory

Applied from dynamical systems theory is the understanding that individuals are self-organizing systems that constantly adapt decision-making algorithms based on continuous informational changes within the environment (Davids & Baker, 2007; Davids, Araújo, Correia, & Vilar, 2013a). Dynamical systems theory identifies that the human system is composed of many independent degrees of freedom which act on different levels within the system (Bernstein, 1967; Davids, 2010). As such, there are many different interacting components which could result in similar functional behaviour. The theory emphasises the influence of multiple constraints on behaviour and proposes a framework through which individual performers satisfy the multiple constraints upon them in dynamic environments (Davids, Araújo, Shuttleworth & Button, 2003).

This implies the suggestion that in order to promote learning, individuals should be exposed to training environments that produce dynamic informational affordances that require individuals to re-organize movement patterns according to new opportunities.

Integrated framework

As such, the ecological dynamics approach acknowledges the importance of creating an evaluation or learning environment that is representative to that of the real performance situation (Renshaw *et al., 2010*). In doing so, individuals are exposed to similar affordances during training as they would in real performance environments. Consequently, results obtained during investigation under representative conditions may be applied to circumstances of real performance situations (Hammond & Bateman, 2009).

This 'representative learning design' (see Brunswik, 1955) is based on the key principles of the ecological dynamics approach: action fidelity and functionality (Pinder *et al.*, 2011). Action fidelity can be described as the degree to which the simulated (training) environment reflects that of the real performance environment (Pinder *et al*., 2011). A training environment closely resembling the real performance environment is referred to as having high action fidelity. Functionality refers to the degree to which the task design maintains functional coupling between perception and action processes (Pinder *et al*., 2011). For example, batting in traditional cricket nets against live bowlers has a high degree of functionality as the coupling between the perception of deliveries and the action of the cricket stroke remains as it would in real performance environments. However, the degree of action fidelity of net batting is relatively low due to the lack of representative task constraints that are present in real performance environments, such as fielders, runs or batting objectives.

The greater the practice environment resembles that of real match situations or experiences, the greater the transition of learned skills (Magill, 1993; Dicks, Davids & Button, 2009; Müller & Rosalie, 2010). Therefore, practitioners are encouraged to create training environments which strongly resemble that of the real performance situations through the use of task designs with high degrees of action fidelity and functionality.

Ecological theorists prescribe the design of learning environments which maintain information-movement couplings that would be representative of real performing situations (Renshaw *et al*., 2010). By creating a representative learning environment, researchers would be able to ensure ecological validity of the environment to that of real performance situations (Pinder *et al., 2011*). For example, the use of a ball projection machine in place of a live bowler during cricket training results in significantly different movement patterns of the feet and bat swing (Renshaw *et al*., 2007). The variation of perception-action coupling when using the ball projection machine compared to the live bowler translates to a loss of functionality of the training design, resulting in movement patterns that would not be replicated in real performance situations. Therefore, from this point of view, the use of a ball projection machine should be used sparingly as it does not provide the visual cues of a live bowler.

Neurobiological degeneracy

Ecological dynamics approach introduces the concept of 'degeneracy' (Pinder, Renshaw, & Davids, 2013: 804), which describes that functionally equivalent actions can be achieved via structurally different movement systems (i.e. numerous degrees of freedom) (Bernstein, 1967; Pinder *et al*., 2013). In other words, it is argued that there is no 'classical' technique for performance; each individual will have different learning dynamics as the interacting configuration of constraints will differ between learners (Chow, Davids, Hristovski, Araújo, & Passos, 2011). Subsequently, different movement patterns develop between individuals with similar performance outcomes achieved. It is important to recognise that individuals may perceive or interpret task objectives or environmental cues differently, yet final performance measures may be similar due to the unique abilities of each individual (Pinder *et al*., 2013). This is important to understand, as traditional net practices focus on the improvement of individual techniques as coaches attempt to mould batsmen's techniques according to a 'classical' approach to cricket batting.

Constraints-led approach

Constraints-led training has been introduced to assist the development of motor learning. Based on the ideologies of ecological dynamics, constraints-led training incorporates the representative learning design (high degree of action fidelity and functionality) along with the understanding of the different constraints involved in performance (Renshaw *et al*., 2010). The constraints-led perspective acknowledges that the cyclical relationship between information and movement is based on the interacting constraints of the individual, the task and the environment (Davids, 2010; Renshaw *et al*., 2010). Therefore, small variations to task or environmental constraints may result in vastly different information-movement systems (Renshaw *et al*., 2010).

The constraints-led approach is governed by the constraints within each of the three-tiered system: individual (organism), environment and task. These constraints are responsible for influencing the acquisition and/or adaptation of motor learning (Araújo *et al*., 2006; Renshaw *et al*., 2009; Davids *et al*., 2013b).

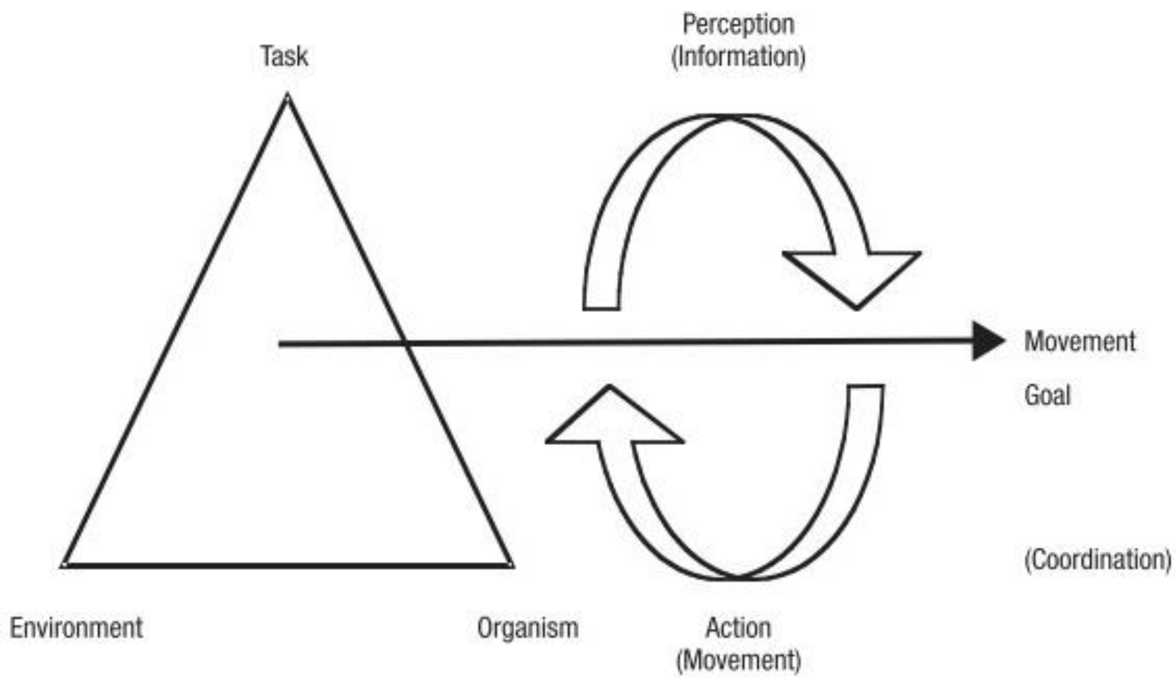

Figure 1: The emergence of coordination and control, in the form of functional information-movement coupling, from the interaction of key constraints on the individual (extracted from Davids, 2010)

Individual (organismic) constraints include aspects of physiology, psychology, cognition, motivation, socio-economic status, geographical settings, and socio-cultural structures (Davids, 2010; Renshaw *et al.*, 2010). Due to various combinations of individual constraints, performers develop unique methods to deal with attaining the relevant goals, resulting in varying degrees of freedom (Davids, Button, & Bennett, 2008). These human-centred factors provide individuals with opportunity for action and are responsible for the style, or manner, in which an individual sets out performing the task (Renshaw *et al*., 2010). For example, physically strong batsmen may approach batting by muscling the ball to various areas of the playing surface, whereas physically weaker batsmen are required to manipulate the ball skilfully in order to accumulate runs.

Environmental constraints include physical aspects such as surroundings (i.e. gravity, altitude, light, and noise), weather conditions, playing surfaces (i.e. location, size, and type of surface), and previous environmental settings of informal gameplay (Davids, 2010; Renshaw *et al.*, 2010; Greenwood, 2014). A cricketing example would be the type of pitch played on which would influence the approach used by batsmen to score runs, such as a hard pitch providing extra bounce which would require a greater amount of back foot strokes.

Finally, and arguably the most important, is the task constraints (Renshaw *et al.*, 2010). These include aspects of gameplay, such as rules and regulations of the activity at hand, the objectives and outcomes for successful performance, and the equipment used during the learning experience (Davids, 2010; Renshaw *et al.*, 2010; Greenwood, 2014). This is an area of gameplay which can be manipulated to shape the emergence of individual behaviours during motor learning (Renshaw *et al.*, 2010; Greenwood, 2014). For example, a cricket coach may alter the rules and regulations of a training session to encourage batsmen to change their normal batting behaviour. This may take the form of scoring constraints, whereby batsmen are only allowed to score runs in certain areas of the field (i.e. straight back passed the bowler). Batsmen may be punished if they play horizontal bat strokes, or if they play the deliveries to third-man or fine-leg. A simple constraint such as this would encourage a different set of action responses from the batsmen in order to succeed with the training session.

The aim of a constraints-led approach to motor learning is to identify the nature of the interacting constraints that influence the skill acquisition of an individual (Davids, 2010). Once this has been identified, learning environments can be created to further assist with the development of motor learning. A well-designed learning environment manipulating informational constraints would constrain individuals to the emergence of functional movement patterns, as well as afford an environment which could shape decision-making behaviour (Davids, 2010).

Part II of this chapter analyses the efficacy of the constraints-led approach in terms of skill development via intervention training within interceptive sports by means of a systematic review.

Motor learning and performance

Motor learning can be defined as a relatively permanent change in the capacity for skilled action, associated with practice and/or past experiences (Kerr, 1982; McKeough & Bagatell, 2009). It is considered 'relative' as learning cannot be measured per se, but is rather inferred based on performance outcomes (McMorris, 2004). Performance, however, is not constant, it fluctuates from one attempt to the next (McMorris, 2004; Hays, Thomas, Maynard, & Bawden, 2009).

The best measure for inferring learning is through the use of a follow-up retention test, performed by the individual sometime after the learning period has been completed (McMorris, 2004). Retention tests alleviate possible misinterpretation of intervention training by eliminating inferences of transient performance effects as functionally significant learning effects (Caserta *et al.*, 2007). It is believed that if learning has truly taken effect, the absence from training for a brief period following the intervention would not alter the level of performance. A major issue in motor learning research is the misinterpretation of grossly simplistic motor tasks as a means to infer learning of more complicated, gross body skills (Wulf & Shea, 2002; McMorris, 2004).

When testing skill proficiency in a cohort experienced with the task in question, it is important to consider the fluctuation of performance which may influence the interpretation of the results. For example, a participant may have a sub-standard performance during a baseline measurement, followed by a standard to good performance in a comparative measure. A researcher may infer that a learning effect has occurred due to significant differences between the two testing sessions; however, this may not necessarily be the case. Likewise could be said for a reverse effect, whereby an individual may have a standard to good performance during the baseline measurement, followed by a sub-standard performance in the comparative measure.

In an ideal scientific experimental design, researchers should afford participants with a number of trials of a task to establish an average performance measure. This may be done one after the other, or over the course of a few days, depending on the constraints involved and the complexity of the task. It should also be done for all performance measures (i.e. pre-test, mid-test, post-test, retention-test), as opposed to comparing once-off task measures. The once-off measures do not account for ‘exceptional’ or ‘poor’ performance fluctuations, which may normalize during the comparative testing procedure. Such instances may result in false positive or false negative outcomes, leading to a misinterpretation of the testing procedure. This is particularly relevant for highly skill-based tasks, with numerous interacting constraints influencing the performance of an individual.

However, when testing skill proficiency in a novice cohort, there is an increased likelihood of a learning effect taking place. Therefore, increasing the number of trials per testing session may provide participants with more exposure and familiarity, resulting in issues of validity and reliability of their true potential. This refers to ‘practice’ trials over and above the initial habituation trial and baseline measurement.

Literature does not indicate a minimum time period by which a change in performance (learning) should occur. Learning is a continuous process that occurs throughout our lives, with no definitive endpoint (Čoh, Jovanovic-Golubovic, & Bratic, 2004). As such, it is difficult to prescribe a length of time (exposure) in which individuals should start showing progress within a given task. Naturally, one would assume that the more complicated the task, the more time (exposure) would be required to learn that task. However, as each individual is unique, there is no general rule that can be used to explain the process of skill acquisition within a complex motor task, such as skill-based sports.

SKILL ACQUISITION

When investigating skilled performance within a sporting context, it is important to understand the factors responsible for the acquisition of skill. Much debate has surrounded the basis for superior performance, from a physiological perspective as well as a motor skill perspective, with theoretical ideologies divided between genetics and deliberate practice (Ericsson, Krampe, & Tesch-Römer, 1993; Baker & Davids, 2005; Davids & Baker, 2007; Tucker & Collins, 2012). The debate has primarily accepted an extremist or dualistic view, with researchers generally adopting one or the other perspective as truth. The following discussion will focus on the original beliefs of the nature versus nurture debate, followed by more recent understandings of the interaction between the two perspectives.

Nature vs. Nurture

The debate between nature and nurture has sparked renewed academic and public interest with the recent release of a number of books' interpretation of talent and the acquisition of elite performance (see Gladwell's *Outliers* (2008); Coyle's *The Talent Code* (2009); and Epstein's *The Sports Gene* (2013)).

Briefly stated, this debate has researchers from molecular biology and behavioural psychology arguing over the basis of elite performance. Molecular biologists believe that elite performance can be traced back to the genetic make-up of individuals; elite athletes are born to succeed due to predisposed genetic characteristics (Davids & Baker, 2007; Tucker & Collins, 2012). As a result, an individual not in possession of the specific genetic characteristics necessary for a given domain will not be able to reach an elite level, regardless of the amount of deliberate practice they perform (Davids & Baker, 2007; Tucker & Collins, 2012).

In terms of motor skill acquisition, researchers have attempted to identify whether genetic influence is responsible for inter-individual differences in skilled performance (Williams & Gross, 1980; Fox, Hershberger, & Bouchard, 1996; Davids & Baker, 2007). Studies have performed measures on monozygotic and dizygotic twins to identify the effect of genetics on inter-individual variance (Williams & Gross, 1980; Fox *et al.*, 1996; Davids & Baker, 2007). These have included measures for balance, as well as pursuit rotor tracking in order to measure performance differences (Williams & Gross, 1980; Fox *et al*., 1996). With the use of identical genetic participants (monozygotic twins), researchers believe to have discovered a greater intra-class correlation of skill acquisition in comparison with dizygotic twins (Fox *et al*., 1996). From these examples it can be suggested that the genetic predisposition of individuals has some degree of influence in the acquisition of elite performance. However, research is still required from a complex motor skill perspective.

From these observations some researchers have become immersed in the philosophy that genes are solely responsible for elite performance (Davids & Baker, 2007). To have a single, tangible measure (genes) to predict future performance would allow for easier understanding of talent development as well as help coordinate future programs to assist with the development of potential candidates.

Consequently, there has been an increase in genetic testing to identify specific genes that are responsible for specific athletic traits (such as muscle fibre composition, receptiveness to training, injury risk, concussion and tendinopathy) (Tucker & Collins, 2012; Guth & Roth, 2013). Researchers and talent identification administrators have become blinded by the idea that elite athletes can be selectively developed through identification of favourable genes. However, the scientific understanding of talent development is far more complicated than this ideology.

Conversely, behavioural psychologists argue that elite performance is the result of innumerable environmental influences and experiences, and that genetics has no role in the development of elite performance (Davids & Baker, 2007; Tucker & Collins, 2012). Researchers here believe that all individuals are born equal and that subsequent performance is developed through deliberate practice and experiences (Ericsson *et al*., 1993; Davids & Baker, 2007). It is believed that elite performance can be attained within any given domain provided that the subsequent number of hours of deliberate practice is fulfilled. Individuals who manage to attain such enormous amounts of hours would therefore be at an elite level of performance. For example, Ericsson *et al*. (1993) studied the correlation between master level chess players and the amount of hours that these individuals spent training (deliberate practice), concluding that to achieve an elite level individuals were required to perform vast amounts of hours in deliberate practice.

The 10,000-hour theory stemmed from this, which prescribed that to achieve an elite level of performance within any given domain, individuals were required to perform a minimum of 10,000 hours (or 10 years) of deliberate practice (Ericsson *et al*., 1993; Davids & Baker, 2007; Gladwell, 2008; Tucker & Collins, 2012). Tucker and Collins (2012) have labelled this perspective as the ‘Practice Sufficiency Model’, describing that in order to achieve skilled performance, an individual merely has to practice a sufficient number of hours.

Tucker and Collins (2012) provide clear evidence against the 10,000-hour theory. The authors noted that Ericsson *et al*. (1993) failed to account for outliers within their final conclusions, who managed to achieve elite performance in significantly shorter time than the proposed 10,000-hour benchmark (Tucker & Collins, 2012). The accumulated training hours of elite performers ranged from ± 3,000 hours to ± 23,000 hours, with one case having failed to achieve the master level despite ± 25,000 hours of deliberate practice (Tucker & Collins, 2012). This suggests that there must be alternative explanations for the differences in skill level despite acquiring a sufficient amount of hours of deliberate practice.

The concerns over an extremist interpretation of elite performance are manifested in the requirements for each perspective to be true. The interpretation of the genetic argument should be considered in more detail. Genetic researchers have been preoccupied with identifying a superior athletic trait within the human genome that can explain discrepancies in superior performance (Tucker & Collins, 2012). However, this misunderstanding has resulted in the introduction of the 'single gene as a magic bullet' philosophy, whereby researchers believe that elite athletes can only be borne in the presence of such a gene (Davids & Baker, 2007).

Yet there is no single gene, currently identifiable, that is responsible for 'talent' (Davids & Baker, 2007). The vast range of genetic variance among superior athletes provides evidence against the notion of a single gene that is responsible for elite performance (Tucker & Collins, 2012). Researchers have only investigated a minuscule number of genetic variations without conclusive evidence to suggest that elite performance resides solely in a 'gifted' gene (Collins, 2013).

Concerns regarding the nurture perspective are underpinned by the fundamental requirements of this view, which Tucker and Collins (2012) give clear evidence to. Firstly, the variance in individuals' performance should be explained entirely by the accumulated deliberate practice time (Tucker & Collins, 2012). Therefore, the individual who has accumulated a greater amount of deliberate practice time will perform better than the individual with less deliberate practice time. Secondly, exceptional performance cannot occur without high volumes of accumulated training (Tucker & Collins, 2012). Finally, individuals who accumulate high volumes of deliberate practice must always achieve expert or elite levels in that specific domain

(Tucker & Collins, 2012). Therefore, individuals who have not amassed a sufficient amount of deliberate practice will not achieve elite performance until the sufficient threshold has been reached. And individuals who have reached this 10,000-hour barrier will be at an elite or expert level.

Discrepancies between the opposing theories may lie in the understanding of skilled performance. Neither perspective has a clear definition of 'skilled performance' or 'ability', which may provide reason for the polarity. Providing a clear definition may offer transparency for theorists and researchers alike. Interesting to note is the absence of the term 'ability' in either perspective, which is often used synonymously with the term 'skill'.

Skill vs. Ability

McMorris (2004) provides a clear definition of skill, describing it as "the consistent production of goal-oriented movements, which are learned and specific to the task" (p.2). This definition of skill can be further refined as "the dynamic exploratory activity, and not the stereotypical reproduction of a static representation of action" (Newell, 1991: 233). From this it can be understood that skill is acquired; it is learned through many hours of deliberate practice within that domain. This definition supports the ideas of the environmental perspective in that skilled performance is acquired through experience and practice.

Ability, however, can be described as the "basic innate action that underlies skilful performance" (McMorris, 2004: 8). In other words, abilities explain the potential for each individual. This supports the ideas of biological scientists in that ability is the result of genetic make-up. Therefore, each individual is born with a unique set of abilities which is predetermined by the genetic make-up of the individual. In order for an individual to obtain the skills required to achieve their abilities, it is essential that individuals engage in sufficient deliberate practice in order to improve those skills.

Providing a clear working definition of skill and ability gives evidence to the complimentary relationship between nature and nurture. Davids and Baker (2007) support the mutuality of the opposing perspectives, suggesting that skilled performance may be the result of "the interactive influence of genetic and environmental constraints" (p.2). Tucker & Collins (2012) rephrase the term 'ability' as an individual's 'maximum potential', which is a limited capacity that cannot be exceeded regardless of the amount of deliberate practice or experience. This understanding of performance capacity has been labelled as the Genetic Ceiling Model (Tucker & Collins, 2012).

Genetic ceiling model

Opposed to the popular debate of nature versus nurture, Davids and Baker (2007) and Tucker and Collins (2012) provide a theory that elite performance results from the optimal interaction of intrinsic (nature) and extrinsic (nurture) factors (Figure 2). Shifting away from the dualist view of elite performance, the genetic ceiling model states that individuals are given an innate, limited ('ceiling') ability that can only be fulfilled through the attainment of skills developed by means of favourable and optimal environmental constraints, such as deliberate practice, coaching, experience and exposure (Tucker & Collins, 2012).

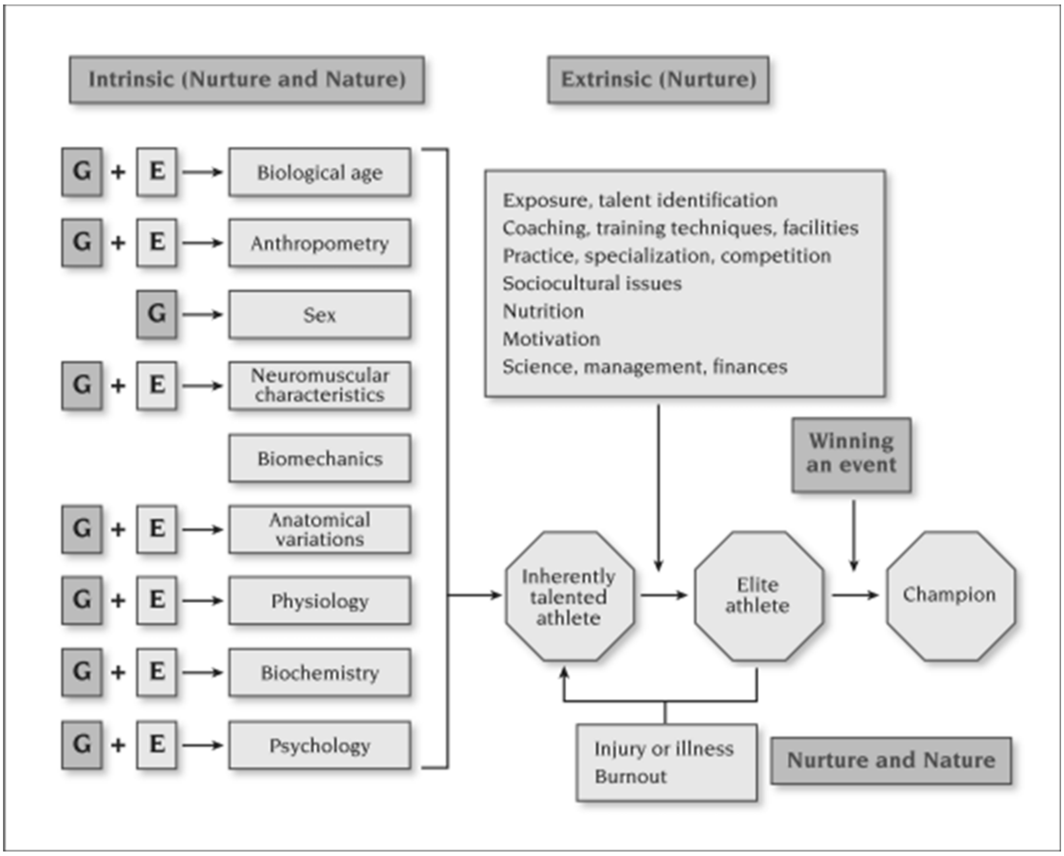

Figure 2: Breakdown of the intrinsic (genetic) and extrinsic (environment) factors that influence the acquisition of skilled performance (extracted from Tucker & Collins, 2012)

According to this model, the level of performance, incorporating subsequent training essential for improvement, has an upper limit or performance capacity which is determined by the genetic predisposition of each individual (Tucker & Collins, 2012). Regardless of the amount of training and practice that is performed by an individual, the upper limit of performance (i.e. the maximum potential) cannot be exceeded (Tucker & Collins, 2012). In order to reach this maximum potential, individuals are required to maximize the extrinsic factors (Figure 2) such as the amount of deliberate practice and exposure to correct coaching techniques to ensure improved performance (Tucker & Collins, 2012). Weissensteiner *et al*. (2008) agree with this understanding of skill acquisition, describing that “the perceptual skills that are known to be critical for expert performance in adults improve not with maturation or chronological age alone but with experience with, and exposure to, vast amounts of task-relevant practice” (p.644).

Inherently talented athletes have greater maximum potentials due to favourable genetic variations, which could arise within any of the intrinsic factors highlighted in Figure 2. For example, elite skill-based athletes may have an advantageous genetic make-up for the neuromuscular characteristics factor which allow for greater motor coordination (Figure 2). Conversely, elite non-skill-based athletes may have an advantageous genetic make-up for the biomechanics factor, which allow for better leverage or efficiency (Figure 2). These combinations of factors result in a unique pathway for each individual, eventually leading to an elite level (Tucker & Collins, 2012).

However, in order for these inherently talented athletes to achieve an elite status, the extrinsic factors that influence development are required to be optimized. This includes superior training regimes, correct nutritional diets, motivation to succeed and so forth (Tucker & Collins, 2012). In the event of injury or burnout, these athletes would lose some of the benefits that arose from optimizing the extrinsic factors, returning to their previous inherently talented status (Tucker & Collins, 2012).

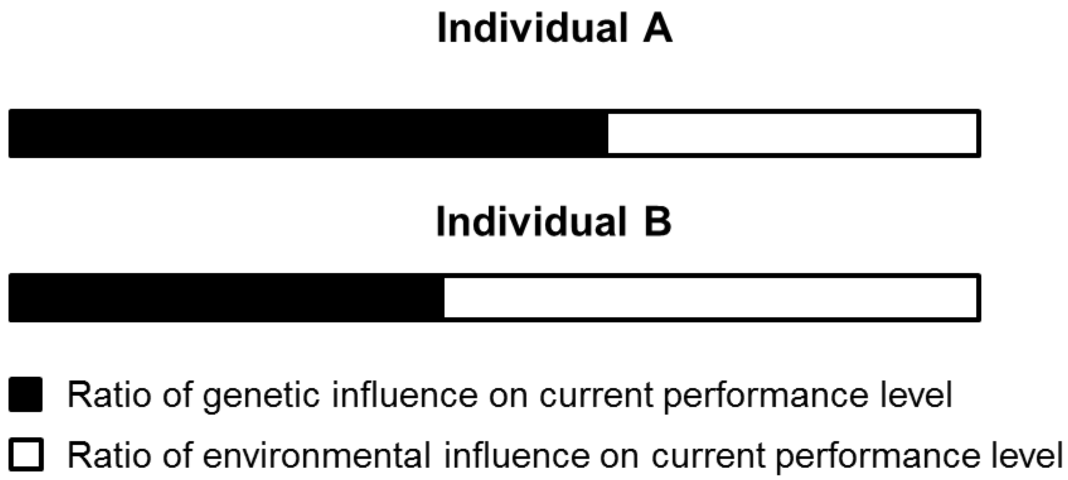

Figure 3: Two individuals, A and B, performing to the same level of elite performance. Individual A has a greater maximum potential, shown by a greater influence of genetics on performance compared to Individual B; however, due to the greater amount of environmental factors such as training and exposure, Individual B competes to the same level as Individual A despite having a lower maximum potential.

In summary, the acquisition of skill is dependent on two variables: the innate ability of each individual and the successful attainment of the necessary skills to achieve an individual's maximum potential, determined by the amount of deliberate practice and exposure to favourable opportunities. There is no singular pathway to becoming a successful athlete, which is illustrated in all domains with vastly different phenotypic profiles, as well as environmental influences, such as training regimes and socio-cultural backgrounds.

Elite athletes are predisposed to their specific domain by an innate ability, however in order to achieve this elite potential sufficient deliberate practice is required. Innate ability is the 'stepping stone' that could lead to skilled performance, however without the correct environmental factors the maximum potential of individuals cannot be attained. With that said, once the optimal and sufficient amount of deliberate practice has been performed, an individual's performance will plateau and increases in performance will cease to occur (Tucker & Collins, 2012).

Why is this important?

Incorporating the complicated influence of the innumerable intrinsic and extrinsic factors (Figure 2) on skill acquisition allows researchers to select and screen possible participants in order to control the effect of different levels of skill on performance assessments and subsequent interpretation. This is an important aspect of the scientific methodology in skill-based sport as the acknowledgment and control of differing levels of skill is crucial for reliable and accurate interpretation of findings.

Due to the difficulty of controlling the effects of intrinsic factors (i.e. biological homogeneity) on skill development, it is important for researchers to 'best-control' the effects of the extrinsic factors, in order to provide some level of equality among participants. Controlling the influence of extrinsic factors, such as selecting groups of individuals from the same sports team that have been practicing together for the same amount of time, allows researchers to identify differences in performance due to the influence of the innate abilities (genetic predisposition) of individuals.

SUMMARY

In summary, adolescent cricket training primarily makes use of the ubiquitous 'net practice'. Although there are some advantages of using such a method, there are a number of factors which limit an efficient learning environment. The major concern is the lack of a representative design to replicate situations of real match play. This comes in the form of fielder-less batting scenarios, therefore making batting 'easier' in these training sessions. However, literature suggests that a learning environment should make the task more challenging, with a greater representation of the real performance environment.

The constraints-led approach emphasises the interaction between individual, task and environmental constraints at numerous levels within the complex human system. Co-ordinated movement patterns, or behaviour, are regulated by the relationship between perception and action systems, with the influence of specific individual, task and environmental constraints. It is believed that specific constraints influence the information sources which regulate human behaviour in varying performance environments. Therefore, the constraints-led approach considers behaviour which emerges from the interaction between the individual and the environment.

Motor learning and the acquisition of skill are important concepts to understand when it comes to sports training. There are many different facets of nature and nurture which play an intertwined role within skill acquisition. It is important for researchers to acknowledge these influences and attempt to control (or account for) as best as possible when interpreting scientific findings. Performance is never a consistent occurrence; it is a fluctuating phenomenon that requires numerous attempts to gauge a norm. As such, evaluation measures should account for these fluctuations and incorporate a design which would allow for the most accurate and reliable measure of each individual's athletic performance.

PART II: SYSTEMATIC REVIEW

THE EFFECTIVENESS OF CONSTRAINTS-LED TRAINING IN SKILL DEVELOPMENT IN INTERCEPTIVE SPORTS: A SYSTEMATIC REVIEW

BACKGROUND

The aspiration for athletic excellence is sustained through the growing spectatorship and economic benefit of professional sport (Baade & Matheson, 2003). Consequently, sports scientists and practitioners are constantly striving to improve human performance by optimising physical-, technical- and/or cognitive-based training regimes. Attention has primarily focused on physical training, with research on the technical and cognitive aspects receiving less work (Williams & Hodges, 2005). The authors' speculate that this may be due to the more obvious limitations of sub-optimal physiological conditioning, commonly seen via injuries and burnouts to athletes, on performance (Williams & Hodges, 2005). In contrast, the performance benefits of technical and cognitive research may not be as apparent. Williams and Hodges (2005) suggest that this may be due to the relative difficulty of evaluating behavioural changes compared with physiological changes.

The technical and cognitive aspects of training are particularly important for skill-based sports, which incorporate multi-articular and coordinated movement patterns to intercept a ball or shuttle. Apart from requiring optimal physiological fitness, interceptive sports such as baseball, cricket, hockey, and tennis, require a significant amount of hand-eye coordination to perform successfully (see Barris, 2013). The complexity of interceptive sports is governed by the temporal and spatial constraints defined by each sport. Therefore, traditional coaching places great importance on the training of these technical and cognitive skills for the enhancement of athletic performance.

Traditional coaching techniques are heavily dependent on the expertise of past generations, often presented in coaching manuals of previously successful sports men and women (i.e. Woolmer, Noakes & Moffett, 2008). The focus is often manifested in teaching the 'perfect' technique required to master a movement pattern, despite the knowledge of 'degrees of freedom' (see Bernstein, 1967 and Newell, 1985) and individual variability. Formal practices are quick to adopt these principles, with coaches often lacking support to experiment with more evidence-based training methods that are becoming more common in sports research.

There has recently been an increase in research investigating the usefulness of alternative methods of technical and cognitive training (Araújo, Davids, & Hristovski, 2006; Renshaw, Davids, Shuttleworth, & Chow, 2009; Davids, Araújo, & Hristovski, 2012). Constraints-led training is a variation from traditional training regimes which provides athletes with a greater representation of the sporting environment in order to train specific match skills (see Renshaw & Holder, 2010). This has been introduced to assist with the development of various skills, techniques and decision-making abilities to further improve performance, as well as improve the quality and quantity of training.

The constraints-led approach was introduced in motor learning to assist with the development of skills and techniques through the manipulation of specific task, individual or environmental constraints (Araújo *et al*., 2006; Renshaw *et al*., 2009). The approach is based on the theory of ecological dynamics, whereby performance is understood to result from the interaction of the individual and the environment (Araújo *et al*., 2006). The ecological dynamics approach perceives humans to be complex, nonlinear, neurobiological systems that act in accordance with unstable, evolving environments to produce movement actions necessary to perform a given task (Renshaw *et al*., 2009; Davids, Araújo, Vilar, Renshaw, & Pinder, 2013). The unstable environments provide individuals with specific "affordances" (*def*. opportunities for action) that influence the outcome of the action required (Fajen, Riley, & Turvey, 2008: p.79).

The approach argues that the training of individuals in isolation of their 'real performance settings' should be viewed with scepticism, as it does not provide the representative affordances that could be expected in 'real performance settings'. Traditional training regimes are prone to focus on the breakdown of movement patterns required for a particular sport. For example, cricket batsmen hone their techniques by means of formal net practices. This breakdown provides 'bite-size' movement sequences to allow for easier training toward a 'correct' or 'perfect' technique. However, the focus on this form of training often neglects the importance of the affordances provided by training in a representative environment. Maintaining the cricket example, batsmen should be afforded the opportunity to train in a 'real performance setting' in order to coordinate the technique with the requirements of the batting task as well as the constraints supplied from the sport's rules and regulations. Incorporating all these aspects might produce a movement action that may differ to the one being trained in the traditional net setting.

The ideology behind the ecological dynamics approach is to design training or evaluation environments that afford individuals opportunities that would be associated with real performance environments (Davids *et al.*, 2013). These environments should allow individuals greater quality (and possibly quantity) of training, thereby providing improved transfer of learning to real world environments. Using a tennis example, manipulating the court size by decreasing the surface area may provide a greater opportunity to prolong rallies for low-skilled participants, therefore increasing the quantity of hitting during training sessions (Farrow & Reid, 2010).

The key principles behind this approach are that of functionality and action fidelity (Pinder, Davids, & Renshaw, 2011). Functionality refers to the degree to which the task maintains the perception-action coupling present in real performance environments; whereas action fidelity refers to the degree to which the training environment reflects that of the real performance environment (Pinder *et al*., 2011). The constraints-led approach encourages the design of a training environment that affords individuals a high level of functionality as well as a high degree of action fidelity.

Most studies on constraints-led training within interceptive sport focus on the manipulation of a single facet within the task in an attempt to provide individuals with alternative means of learning task-relevant skills. For example, Stretch, Nurick and McKellar (1998) attempted to train cricket batsmen to improve their accuracy of hitting the ball in the middle of the bat; this was done through the use of a modified bat, one-third the width of regulation size (Stretch *et al.*, 1998b). However, constraints-led training may make use of multiple constraint manipulations to provide individuals with improved methods of training while maintaining the principles of the ecological dynamics approach.

Currently, there is a lack of sufficient evidence to advocate whether the manipulation of specific task constraints benefit individuals more so than traditional training regimes. To the authors' knowledge, there are no review papers which summarize the evidence for or against constraints-led training intervention studies, specifically relating to interceptive sports. As such, the purpose of this review is to systematically examine the current status of the literature specifically relating to the effects of constraints-led intervention training on skill development within interceptive sports. The review will also critically compare and discuss the strengths and weaknesses of the various methodologies used to investigate the effects of these interventions.

METHOD

Search strategy and study selection

The search strategy made use of four online databases to locate and retrieve journal articles that were sourced using an array of keywords and phrases (Table 1). The multidisciplinary databases of Google Scholar, JURN, Mendeley, and Science Direct were searched from February 2013 to September 2015 with no publication date restrictions. The 'advanced search' option was selected within the Mendeley and Science Direct databases. The disciplines of 'Education', 'Psychology' and 'Sports and Recreation' were selected within the Mendeley database in an attempt to reduce the number of irrelevant journal articles. The remaining databases were searched in their entirety for relevant open-access journal articles, with the 'advanced search' option proving ineffective. The keywords related to skill development, intervention training, constraint manipulation and interceptive sport. Reference lists within journal articles were scanned to source further related articles.

Table 1: Keywords and phrases used to search each database

Skill	Improvement	Interceptive sport	Constraint-led	Intervention
Technical skill	Development	Interceptive action	Manipulation	Practice
Motor skill	Acquisition	Cricket/Baseball	Task requirements	Training
Co-ordination		Tennis/Hockey	Ecological dynamics	Learning

Potential articles underwent a three-phase screening process (Figure 4). The initial phase of screening was performed on the title, this was followed by the screening of the abstract, and finally the full text was read and screened for selection. Ten articles were arranged per a search page; with a search ending when five consecutive pages were screened without a relevant title article. The selection of studies to be included for review followed a specific inclusion/exclusion guideline (Table 2).

Table 2: The inclusion and exclusion criteria used during the screening process

Inclusion criteria	**Exclusion criteria**
➢ Intervention training	➢ Dissertations not peer-reviewed
➢ Interceptive sport	➢ Physiological/ biomechanical effects
➢ Constraint manipulation	
➢ Skill-based assessments	
➢ Peer-reviewed publications	

Data extraction

The extracted data included the population characteristics, type of interceptive sport, constraint manipulated, intervention design, number of training sessions afforded to the participants, and the overall outcome effect of the intervention that was implemented.

Quality assessment and reporting guidelines

Quality assessment checklists from the Cochrane Collaboration Handbook 5.1.0 (http://handbook.cochrane.org/) were consulted and a reporting guideline was obtained from the EQUATOR Network (www.equator-network.org/) in order to assess the quality of the methodology and reporting within each study. It is important to note that 'methodological quality' and 'reporting quality' are not interchangeable terms, as is commonly implemented in practice (da Costa, Cevallos, Altman, Rutjes, & Egger, 2011). Methodological quality refers to "the appropriateness of the methods employed in the design and conduct of epidemiological research, which determines the reliability of findings (i.e., internal validity)" (da Costa *et al.*, 2011: p. 4). Reporting quality refers to "the completeness with which a study is presented and whether major items for the proper appraisal of internal and external validity of findings are clearly reported" (da Costa *et al*., 2011: p. 4).

The quality assessment tool used to appraise the methodological quality of studies was the domain-based evaluation tool recommended by the Cochrane Collaboration (Higgins & Green, 2011). This tool is used to evaluate the design of the research methodology, providing a risk of bias score for each study (Higgins & Green, 2011). The tool takes into account the randomisation of participants; blinding of participants, researchers, and outcome assessments; as well as incomplete data and selective reporting. This assessment was performed to appraise the risk of bias within each study.

As the studies included in the review were of a case-control nature, a specific reporting guideline was required to assess reporting quality. The STROBE checklist for case-control studies was extracted from EQUATOR Network and used to assess the reporting quality of the studies included for review. The STROBE checklist was designed to assess whether key aspects of the study are reported throughout the article (da Costa *et al*., 2011). There are 33 items in the STROBE reporting guideline relating to important aspects of the study design. The item topics can be seen in Table 3.

Table 3: Item topics measured within the STROBE checklist

Background	Objectives	Study design	Setting	Participants
Variables	Data sources	Bias	Study size	Quantitative variables
Statistical methods	Descriptive data	Outcome data	Main results	Other analyses
Key results	Limitations	Interpretation	Generalisability	Funding

RESULTS

Screening process

The keyword search for the online databases resulted in a match of 1,894,140 journal articles (duplicates not accounted for), of which 164 were retrieved based on title, abstract and keywords. Once these articles were retrieved, abstracts were screened against the inclusion/exclusion criteria (Table 2), resulting in the inclusion of 61 journal articles. These articles were read in full text, with 14 articles satisfying the inclusion criteria and which were included for review. Figure 4 provides detail of the screening process as well as explanation for articles excluded during each screening phase.

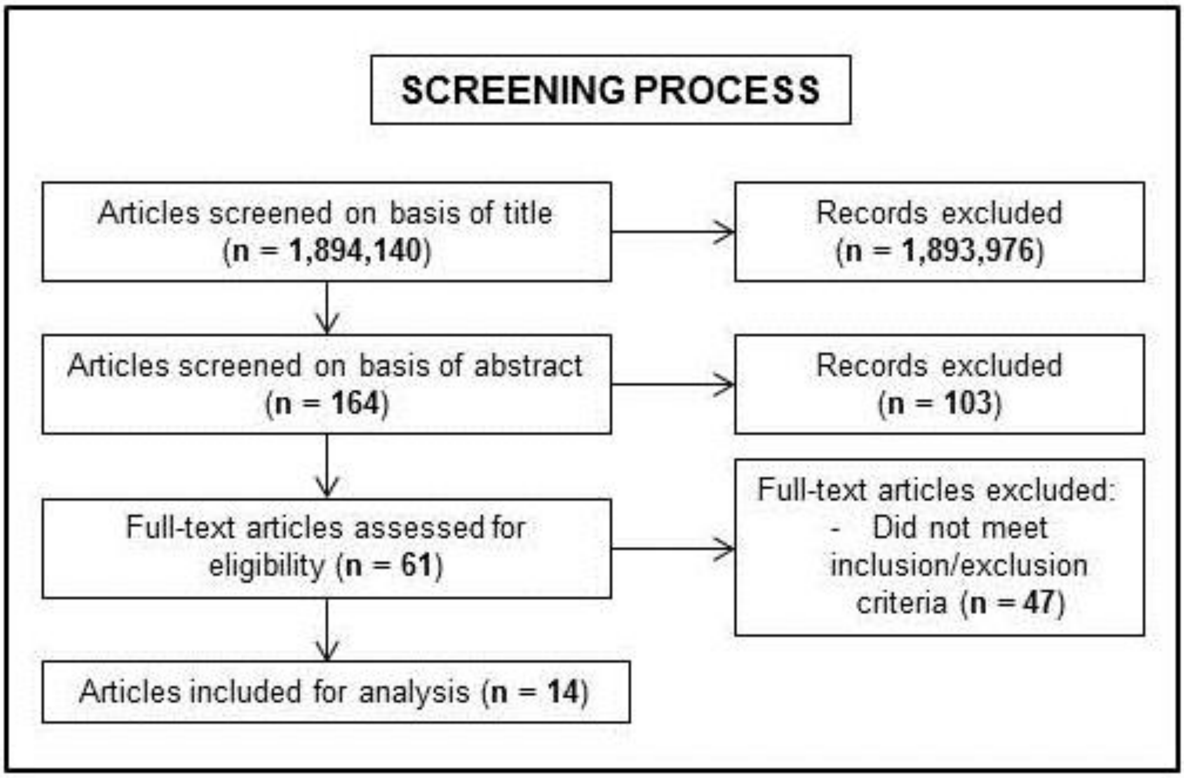

Figure 4: The screening process of journal articles for study selection

Study characteristics

In total, 651 participants across 14 studies were included in the analyses along with three types of constraint manipulations (Table 4). Six studies were on adult participants, five studies on minors and three studies included both adults and minors.

Table 4: Study characteristics summary

#	Study	Sport	Intervention	Population	Participation (n=)	Training Sessions	Outcome Effect
1	Caserta *et al*	Tennis	Informational	> 50 years	Intervention[1] 8 Intervention[2] 9 Control 10	5	√
2	Farrow and Reid	Tennis	Spatial	7-9 years	Intervention[1] 6 Intervention[2] 5 Intervention[3] 6 Control 6	5	√
3	Hagemann *et al*	Badminton	Informational	18-35 years	Intervention[1] 23 Intervention[2] 20 Control 20	1	√
4	Hernandez-Davo *et al*	Tennis	Informational	10-15 years	Intervention 15 Control 15	12	√
5	Masters *et al*	Table tennis	Informational	18-25 years	Intervention[1] 17 Intervention[2] 18	1	**X**
6	Mazyn *et al*	Catching	Perceptual	16-30 years, female	Intervention 8 Control 9	8	√
7	Moradi *et al*	Basketball	Perceptual	16-19 years, male	Intervention 14 Control 14	15	**X**
8	Raab *et al*	Table tennis	Informational	8-15 years	Intervention 10 Control 10	45	**N/A**
9	Stretch *et al*	Cricket	Spatial	16-24 years, male	Intervention 9 Control 9	15	**Both***
10	Turner and Martinek	Field hockey	Informational	11-14 years	Intervention[1] 30 Intervention[2] 30 Control 11	15	√**
11	Vickers *et al*	Baseball	Informational	18-38 years	Intervention134 Control 115	5	**Both***
12	Williams *et al*	Tennis	Informational	18-25 years, male	Intervention[1] 8 Intervention[2] 8 Intervention[3] 8	3	√
13	Williams *et al*	Football	Perceptual	12 years, male	Intervention[1] 6 Intervention[2] 6 Control 6	1	**X**
14	Ryu *et al*	Football	Perceptual	19-26 years, male	Intervention[1] 9 Intervention[2] 10 Control 9	7	√**

* The effectiveness of the intervention was dependent on the level of skill of the participants.

** Control groups were either trained in a different sport code or were afforded no training sessions.

Methodological quality scores

From the domain-based quality assessment guideline obtained from the Cochrane Collaboration Handbook (v5.1.0), the following results for methodological quality were found for the risk of bias within each study.

Table 5: Total quality assessment scores (0-12 scale) which were obtained by assigning studies 1 point for 'unclear' and 2 points for 'high' bias ('low' risk resulted in zero points)

#	Authors	Sequence generation	Allocation concealment	Participant blinding	Outcome blinding	Incomplete outcome data	Selective Reporting	Total quality assessment
1	Caserta *et al.*	Low	Unclear	High	High	Low	Low	**5**
2	Farrow & Reid	Unclear	High	High	High	Low	Low	**7**
3	Hagemann *et al.*	High	High	High	High	Low	Low	**8**
4	Hernandez-Davo *et al*.	High	High	High	High	Low	Low	**8**
5	Masters *et al*.	Low	High	High	High	Low	Low	**6**
6	Mazyn *et al*.	High	High	High	High	Low	Low	**8**
7	Moradi *et al.*	High	High	High	High	Low	Low	**8**
8	Raab *et al*.	Unclear	Low	High	High	Low	High	**7**
9	Stretch *et al.*	Low	High	High	High	Low	Low	**6**
10	Turner & Martinek	High	High	High	High	Low	High	**10**
11	Vickers *et al.*	Low	High	High	High	Low	Low	**6**
12	Williams *et al.*	High	High	Low	High	Low	Low	**6**
13	Williams *et al.*	High	High	High	High	Low	Low	**8**
14	Ryu *et al*	Low	High	High	High	Low	Low	**6**

The result of the methodological quality assessment is summarized in Table 5. The total quality assessment ranged from five to ten out of a maximum 12 points. The greater the score the greater the risk of bias is within the study. Eight of the studies had more than half the maximum points, indicating a high risk of bias within those studies. These assessment scores need to be interpreted along with the reporting quality assessment scores in order to discuss possible reasoning behind different levels of success among the studies included.

Reporting quality scores

From the reporting guideline checklist, the following scores successfully satisfied the specific items (n = 33) of the checklist:

Table 6: Results from the reporting guideline (higher scores reflect better reporting)

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Mean (SD)
Score	19	15	8	13	12	13	12	12	13	16	13	16	13	14	**13.5** (±2.53)
%	57.6	45.5	24.2	39.4	36.4	39.4	36.4	36.4	39.4	48.5	39.4	48.5	39.4	42.4	**40.9** (±7.7)

The result of the reporting quality assessment is summarized in Table 6. The greater the percentage score, the better the reporting quality of the study. The average number of items reported in the studies was less than half of the 33 items (M = 13.5 *(*40.9%); SD = 2.53). Caserta *et al*. (2007) reported the greatest number of items within their study (n = 19; 57.6%), with Hagemann *et al*. (2006) reporting the least (n = 8; 24.2%).

DISCUSSION

Outcome effects

The main discovery from this systematic review was that there was no clear evidence to adjudicate whether constraints-led intervention training had a greater benefit for technical skill development compared to normal training regimes. As only eight (57%) of the studies favoured the constraints-led approach, a precise position on the implementation of this approach could not be made. Had a greater percentage of studies (i.e. ± 75%) showed significant benefit for constraints-led training, a stronger position statement could be made.

The training interventions had mixed outcomes, with eight studies finding significant performance improvements for constraints-led training, three studies finding no effect, two studies finding an effect for a particular skill level, and one study failing to complete analysis due to a questionable study design (Table 4). Raab *et al*. (2005) failed to measure objective performances for the control group and therefore the eventual outcome of the constraints-led intervention could not be compared to the experimental group. To accept this result as valid and reliable would be incorrect and as such, the outcome effect of this study has been excluded from discussion. The study has not been completely removed from the review as it is still valid for discussion on strengths and weaknesses of constraints-led training methodology.

Of the two studies that found a significant effect for a particular skill level, one study (*Study 9: cricket*) found results that benefited only unskilled cricket batsmen, with no benefit shown for skilled batsmen (Stretch *et al*., 1998b). In contrast, the other study (*Study 11: baseball*) found that a constraints-led approach benefited intermediate to advanced baseball hitters rather than novices (Vickers, Livingston, Umeris-Bohnert, & Holden, 1999). In this latter study, novice baseball hitters had greater benefit from normal training regimes compared to the constraints-led technique implemented in the intervention (Vickers *et al.*, 1999). While both these findings are important for constraint-led training literature, the results cannot be categorized into the significant effect grouping as only a certain demographic benefitted from this particular training.

Two studies (S*tudy 10: hockey* and *Study 14: football*) compared effects of different training interventions across two experimental groups and one control group (Table 4). However, the control groups within each of these studies were either trained in a different sport (*Study 10*), or weren't afforded the opportunity to train (*Study 14*). As such, the authors excluded the comparison with these controls groups from their analysis of the studies. The comparison between the two intervention groups within each study were used for the analysis of the effectiveness of these constraints-led training interventions.

Strengths and limitations: Methodology

One of the objectives of this review was to discuss the strengths and weaknesses of the methodology of the included studies to assist with the future development of methodology within this field of research.

The result of the methodological and reporting quality assessments found that both measures averaged less than half of the items for the included studies (see Tables 5 and 6). However, neither the reporting quality nor the methodological quality was able to predict reason for positive or no effect, as important aspects of the studies were not assessed. These important aspects include the sample size, length of intervention, study design and level of participants' skill. Therefore, these areas would need to be assessed more carefully to gain an understanding of the quality of the results of each study:

Sample size

More than half of the studies (n = 8) had relatively small sample sizes, between six and ten participants per group, which may have had an impact on the reliability of the results. Consequently, the outcome effect of these studies may have been distorted. Of the studies with small sample sizes, only one study had no effect for constraints-led training (Williams, Weigelt, Harris, & Scott, 2002: *football*), one study had questionable methodology and was therefore removed from discussion (Raab *et al*., 2005: *table tennis*), and the remaining six all showing some signs of benefit for the experimental group (Stretch *et al*., 1998b: *cricket*; Caserta *et al.*, 2007: *tennis*; Williams, Ward, Smeeton, & Allen, 2004: *football*; Mazyn, Lenoir, Montagne, & Savelsbergh, 2007: *catching*; Farrow & Reid, 2010: *tennis*; Ryu, Kim, Abernethy, & Mann, 2013: *football*).

Intervention period

Seven studies made use of a very short intervention training period, ranging between one and five sessions overall, which may have influenced the reliability of the results. Three studies made use of only one session for the intervention (Williams *et al.*, 2002: *football*; Hagemann, Strauss, & Cañal-Bruland, 2006: *badminton*; Masters, Poolton, Maxwell, & Raab, 2008: *table tennis*), one study consisted of three intervention sessions (Williams *et al*., 2004: *tennis*) and the remaining three studies had five intervention sessions each (Vickers *et al*., 1999: *baseball*; Caserta *et al.*, 2007: *tennis*; Farrow & Reid, 2010: *tennis*).

Two studies, both one session in length, had no effect for the constraints-led approach (Williams *et al*., 2002: *football*; Masters *et al*., 2008: *table tennis*); whereas the remaining five studies had some benefit of the training intervention (Vickers *et al*., 1999: *baseball*; Williams *et al*., 2004: *tennis*; Hagemann *et al*., 2006: *badminton*; Caserta *et al*., 2007: *tennis*; Farrow & Reid, 2010: *tennis*).

The length of the training intervention should be scrutinized as the period should afford participants with an adequate opportunity to learn and develop. An intervention period of between one and five sessions does not allow sufficient time to train under the comparative training regimes (constraints-led vs. traditional training).

The length of intervention should reflect the complexity of the skill required for each specific sport

Study design

Experimental vs. Control: When investigating the possible effects of a training intervention, making use of a case-control study design allows for the best comparison. Some of the studies included in this review made use of experimental and control groups for comparison, whereas other studies made use of two or more experimental groups to compare the effects of the training intervention.

One study showed bias towards the experimental groups, with 85% of the participants assigned to one of two experimental groups (Turner & Martinek, 1999). The remainder of the participants were assigned to the control. This setup engenders unreliable results, due to a greater amount of data for the experimental group/s.

Cross-over design: A good measure to counteract a small sample size is a cross-over trial design. This allows both groups to experience the effects of the training intervention, therefore providing strong evidence for its success or failure. A study, with a relatively small sample size, made use of a cross-over design (Williams *et al*., 2002: *football*), however it found no constraints-led training effect.

Retention tests: Retention or follow-up tests are used with some success in intervention studies to determine the type of learning effects that are found following the intervention period (Caserta *et al*., 2007: *tennis*). Retention tests allow researchers to determine whether participants experience transient performance, or functionally significant learning effects (Caserta *et al*., 2007).

Four studies made use of retention tests to identify the type of learning effect that was found (Vickers *et al*., 1999: *baseball*; Hagemann *et al*., 2006: *badminton*; Ryu *et al.,* 2013: football; Moradi, Movahedi, & Salehi, 2014: *basketball*). Vickers *et al.* (1999), Hagemann *et al.* (2006) and Ryu *et al.* (2013) found that there was greater benefit following the intervention period, indicating functionally significant learning effects. Moradi *et al.* (2014) found no effect following the retention test.

Controlled training: Only one study controlled the amount of additional practice that participants could perform outside of the allocated intervention training period (Farrow & Reid, 2010: *tennis*). This ensured that all participants were exposed to the same amount of training throughout the intervention phase, negating any performance effects due to the volume of training hours.

The remaining studies neglected this aspect, with the possibility that participants may train over and above the intervention requirements. Consequently, findings from such studies may be misinterpreted.

Participant skill level (Experience)

Two studies accounted for skill level within the methodological design. While one study found that unskilled individuals experienced greater benefit than skilled individuals in a constraints-led training drill (Stretch *et al.*, 1998b: *cricket*), the other study found that intermediate to advanced participants experienced greater benefit compared to novice individuals (Vickers *et al*., 1999: *baseball*).

Incorporating skill level within the study design has its own strengths and weaknesses. On the one hand, making use of different skill levels allows researchers to identify specific methods for different skill levels. On the other hand, this design complicates the overall effectiveness of the training intervention, as it might only be successful to a specific group. As such, the results of these two studies made it difficult to categorize the effectiveness of constraints-led training, as it found the training technique to be beneficial to some and not to others.

Strengths and limitations: Quality assessments

The results from the methodological and reporting quality assessments should be investigated further to gain a true understanding of their meaning. Firstly, the reporting guideline is just that, a guideline for epidemiological studies to ensure that a quality assessment can be performed on the internal and external validity of the study design (see da Costa *et al*. 2011). Some items are essential for a scientific paper and these have, for the most part, been correctly documented within the included studies. However, other items within the guideline are not necessary for the production and publication of a scientific research paper, and are understandably overlooked when writing up the final draft.

The reporting guideline takes into consideration a whole range of items (see Table 3) without weighting each item according to greater importance. As a result, some studies may have reported a number of minor aspects of the research study, but failed to include some essential information resulting in a higher reporting quality than other studies (Table 3). As such, the guideline may result in a relatively low reporting quality of the studies included for review.

In terms of the quality assessment scores, the methodological quality of the study is determined according to the risk of bias, with three of the six items concerned with participant or researcher blinding. Therefore, if studies fail to incorporate blinding in the study design, they are predisposed to a high risk of bias due to the number of the items relating to that specific area. Most of the studies included in this review did not perform blinding procedures and therefore scored 'high' for risk of bias (Table 5). However, other important methodological designs such as sample size, intervention period and the control of additional training sessions were not accounted for in any assessments and these should be considered important aspects that may have an influence over the outcome of the training interventions, and therefore the quality of the study design.

END NOTES

Due to the polarity of findings from the studies, a significant outcome for the implementation or rejection of the constraints-led approach within interceptive sport could not be determined. This provides the opportunity for researchers to collect more compelling evidence to answer the question: '*Does constraints-led intervention training assist with the development of technical skills within interceptive sport*'?

The studies had sub-standard quality levels in terms of whole-study reporting as well as methodological risk of bias. There were certain characteristics across each study which either benefitted or hindered the quality of the results. These include aspects such as the sample size, the length of the intervention period, the type of study design and the skill level of participants.

It must be clarified that the review of the constraints-led approach with the use of the included studies indicates that researchers should be reminded of the intent and content of the ecological-psychological approach to motor learning. The misinterpretation of "ecological" can have a significant influence on the outcome of future research, with fundamental flaws in the design of experimental setups.

Future research should consider implementing better quality control in the methodological design. For small sample sizes, consideration should be given to the use of cross-over trial designs in order to strengthen the reliability of the results. Retention tests could be used to determine the type of learning (if any) that occurred as a result of the intervention. Depending on the type of intervention, participant skill and/or experience level are important factors to consider.

LIMITATIONS TO INTERVENTION STUDIES

Depending on the target population and the type of intervention put in place, intervention studies may come with limitations of their own. Firstly, implementing an intervention within a controlled sports environment requires the cooperation from a number of parties, including prospective coaches, players and possibly parents (for minors).

A further limitation relates to the type of sport receiving the intervention, including the length of season (if it is a seasonal sport), the influence of weather on practice/ participation (if sport is played outdoors), or any other factors that may influence the controlled flow of the intervention period.

Sport coaches may find it difficult to understand the need for stringent control across all variables during the study protocol, as they are not accustomed to the required standards of scientific research. Therefore, it is important for researchers to educate sport coaches about the necessity to control all aspects of the training procedure in order to be able to identify where differences may occur, which may in turn detract from cooperation with the research study altogether.

CHAPTER III

METHODOLOGY

STUDY I: PROFILING DATABASE

RESEARCH AIM

The aim of this study was to establish a profiling database of anthropometric, morphological and physical performance characteristics of adolescent cricket players in the Eastern Cape province of South Africa. Correlations between these measurements would be performed to assess the relationships between variables. A secondary aim of the study was to provide insight into the differences between various playing positions in a cricket team, as well as age-related differences for the variables selected. Month of birth effects would also be assessed.

STUDY DESIGN

A once-off test design was implemented to establish a database of anthropometric, morphological and physical performance characteristics of South African adolescent cricket players. Five, well-established cricketing schools in the Eastern Cape province of South Africa were chosen to represent the target population. The geographical location of the research institution, Rhodes University, was the reason behind this selection. The period of data collection was performed prior to the commencement of the 2015/16 cricket season, while participants were engaged in their respective winter sports (May to August 2015). Data collection took place outdoors on a sports field provided by each respective school.

PARTICIPANTS

Ninety (n = 90) participants were recruited for voluntary participation in this study through means of electronic contact of each respective coach. Two age groups were included, under 13 (u13: n = 40) and under 15 (u15: n = 50), for investigation to assess and compare profile discrepancies. The sole eligibility criterion was that participants were required to be members of the top two cricket teams in their respective age groups (A- and B-team players only). Ethical approval for human involvement was granted from the Rhodes University Ethics Committee (RU-HSD-15-05-0005), while informed consent was received from each of the participants and their respective coaches, parents and headmasters (*Appendix A*).

VARIABLES, PROTOCOL AND INSTRUMENTATION

The anthropometric and morphological variables included for analysis were: stature (mm), mass (kg), limb length (mm), flexibility (mm), and body composition (BMI and body fat percentage). The physical performance variables included in the study were: standing jump (cm), overhead medicine ball throw (cm), rotational medicine ball throw (cm), and agility (seconds). Body composition, power, and agility variables were repeated three times, with the average score calculated for analysis (*Appendix C*).

Stature and Mass

Participants' stature was recorded using a tape measure. The tape measure was attached to a nearby wall where stature would be recorded. Each participant was instructed to remove shoes and/or headwear before having their measurement taken. Participants were asked to stand in an upright position, with feet together and pressed against the base of the wall, with hands to their side. The measurement was taken during inspiration (inhalation), at the highest point of the participant's head.

Participants' mass was recorded using a digital scale (SBS150, Sunbeam, Johannesburg, South Africa). Each participant was instructed to remove any footwear, headwear and/or unnecessary clothing before stepping onto the digital scale. Once on the scale, participants were instructed to remain as still as possible, while the scale measured their body mass to the nearest 0.1 kg.

Limb length

Limb length was measured using a dressing tape, with the researcher measuring the upper and lower arm and leg of the right half of the body. The upper arm was measured from the acromion process to the lateral epicondyle, and the lower arm was measured from the lateral epicondyle to the lateral styloid process. The upper leg was measured from the greater trochanter to the fibula head, while the lower leg was measured from the fibula head to the lateral malleolus. Each of these anatomical positions is easily located from the surface of this skin, allowing for consistent measurements to be made. All measures were recorded in millimetres.

Flexibility

The flexibility of the hamstrings, shoulder and trunk of each participant was measured using a sit-and-reach board, a dressing tape measure, and a wooden rod. The flexibility tests utilized for measurement are illustrated in Figures 5 to 7.

Figure 5: Illustration of the sit-and-reach board measuring hamstring flexibility (extracted from Google images search)

Hamstring flexibility was measured using the sit-and-reach board. Participants were instructed to sit on the ground with their legs outstretched against the sit-and-reach board. From here they were informed to slowly slide the adjustable block down the board until they were unable to push any further. The reading at this stage was then recorded.

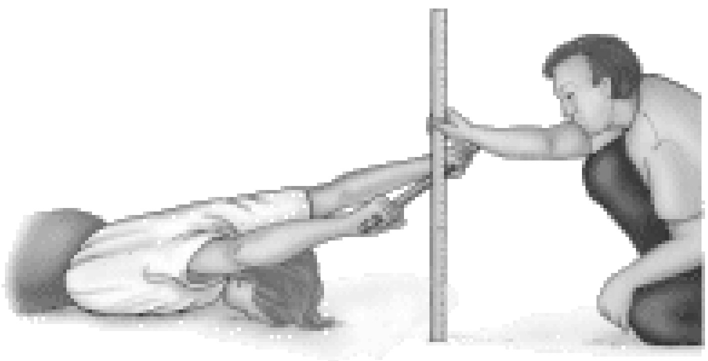

Figure 6: Illustration of the shoulder extension test (extracted from Google images search)

Shoulder extension was measured using a wooden rod and a dressing tape. Participants were instructed to lie in the prone position (face down) as shown in Figure 6. From here, participants were required to lift the wooden rod, with outstretched arms, as high as they could and hold this position for two seconds. Participants were reminded that their feet, hips and forehead were to remain grounded throughout the measure. The researcher would then record the value.

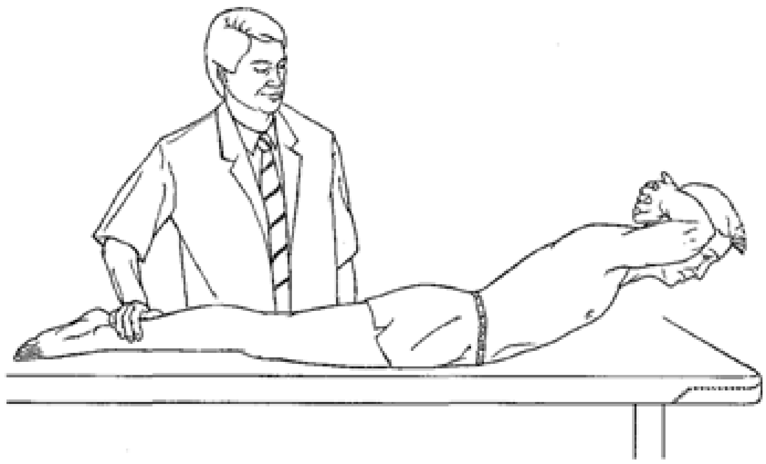

Figure 7: Illustration of the trunk extension test (extracted from Google images search)

The trunk flexibility was measured using the trunk extension test illustrated in Figure 7. Participants were informed to lie on the ground in the prone position with their hands behind their head. From here, they were required to lift their chin as high off the ground as possible, and hold this position for two seconds. Participants were reminded that their feet and hips were to remain grounded throughout the measure. The researcher recorded the distance from the ground to the chin using a dressing tape measure.

Body composition

Body density was measured using the seven-site skinfold method. A skinfold calliper (HaB Direct, Southam, England) was used to measure the surface fat at the following sites: chest, triceps, subscapular, axilla, suprailiac, abdominal, and thigh. This was repeated three times each, with the mean recording calculated for analysis.

Figure 8: Illustration of the skinfold technique for the *triceps brachii* (extracted from Google images search)

The body density (BD) of each player was calculated using the equation devised by Jackson and Pollock (1978) for males (Equation 1). From here a body fat percentage (%BF) was calculated using the Siri equation (Equation 2) (Jackson & Pollock, 1978).

$$\textbf{BD} = 1.11200000 - 0.00043499(\text{sum of 7 skinfolds}) + 0.00000055(\text{sum of 7 skinfolds})^2 - 0.00028826(\text{age}) \qquad (eq.\ 1)$$

$$\textbf{\%BF} = (495 / \text{body density}) - 450 \qquad (eq.\ 2)$$

Power

Power was measured using the techniques of the overhead medicine ball throw, the rotational medicine ball throw, and the standing jump test. A 3kg medicine ball (Headstart, 3kg, India) was used by all participants. Participants were required to perform each test three times, with the average distance calculated for analysis.

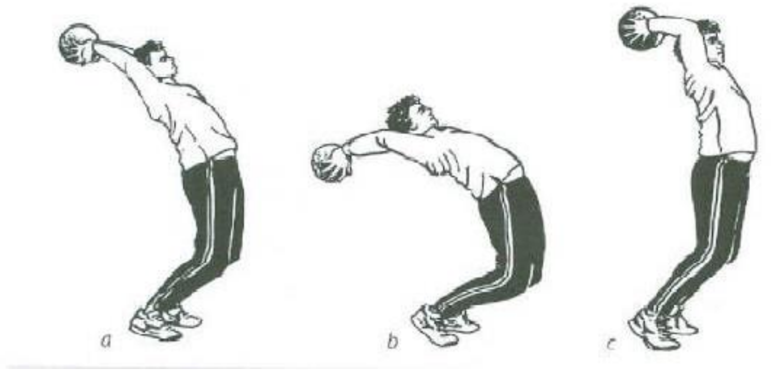

Figure 9: Illustration of the overhead medicine ball throw (extracted from Google images search)

Participants were informed of the correct technique to perform the overhead medicine ball throw, and were instructed that they would be given three opportunities to throw the ball. The average distance of these throws were calculated for analysis. Participants that threw the ball incorrectly were instructed to throw again. The researcher recorded the ground distance from the participant's feet to the point where the medicine ball landed, to the nearest centimetre.

Figure 10: Illustration of the rotational medicine ball throw (extracted from Google images search)

As with the overhead throw, participants were instructed on the correct technique to perform the rotational ball throw. Participants were afforded three attempts for each side, with the average distance calculated for analysis. Participants that threw the ball incorrectly were instructed to throw again.

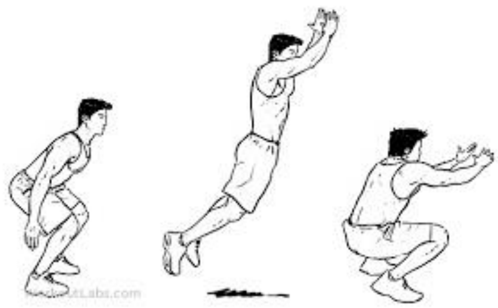

Figure 11: Illustration of the standing jump test (extracted from Google images search)

The standing jump test was used to gauge the explosive power of the lower body. Participants were required to stand on a set line, and leap forward as far they could. Participants were instructed on the correct manner in which the jump could be performed. This was performed three times, with the average distance calculated for analysis.

Agility

Agility was measured through the use of the Illinois agility test (Figure 12). The sequence of the test is illustrated in Figure 12. Eight plastic cones were set out to the measurements described in the figure.

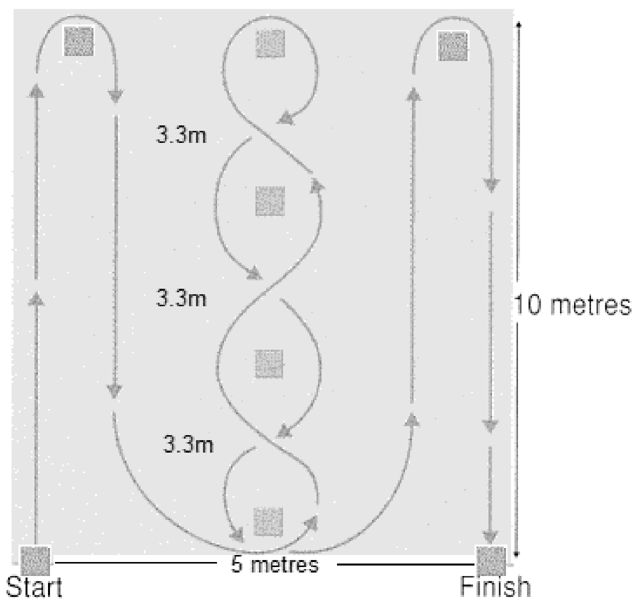

Figure 12: Illustration of the Illinois agility test (extracted from Google images search)

Participants were required to perform the test three times, with the average time to complete calculated for analysis. A stopwatch (Medalist, China) was used to record the times of each participant.

PROCEDURE

The testing protocol was divided into four stations, with each station recording a different variable. This was designed to increase the efficiency of the testing session. Participants were divided evenly into four groups, one for each station. Each group performed the requirements of each station, and once all participants were complete, rotated to the next station in the sequence. Each station was supervised by either the lead researcher or a research assistant (n = 3). Potential bias in testing procedures was minimized by assigning the same research assistant to each station across the testing sessions. As a result, objective measures were recorded by the same assistants across each training session. Before participants were divided into their groups, they were instructed to perform a light warm-up with a mixture of static and dynamic stretches.

Station One: Flexibility and Limb Length

The first station was designated as the flexibility and limb length station. Here a research assistant would inform the participants of the correct technique for the procedure at that station. The flexibility of the hamstrings, shoulder and trunk were recorded. The hamstring flexibility measure was recorded using the sit-and-reach board (Figure 5).

Shoulder and trunk extension were recorded using a dressing tape measure. For the shoulder extension measure, participants were required to lie on the ground in the prone position (face down), with the feet, hips, and forehead resting on the ground. The arms were outstretched in front of the head, holding a wooden rod. The participants were informed to lift the rod, with straight arms, as high as they could and hold the position for two seconds (Figure 6). The researcher in charge of that station would then measure the distance from the ground to the wooden rod.

Trunk extension was performed similarly to this, but the participants were informed to place their hands behind their head while they lay in the prone position on the ground. Again, participants were instructed to keep their feet and hips on the ground throughout the procedure. The participants were then required to lift their chin as far off the ground as possible, and hold this position for two seconds (Figure 7). The researcher would then record the distance from the ground to the chin with the dressing tape measure.

Station Two: Body Composition

The second station was designated as the body composition station. Here the researcher responsible for this station would explain the procedure that would be required of the participants. The seven-site skinfold method was implemented to establish the body composition of participants using a skinfold calliper (Figure 8). The researcher would mark out the seven areas that would be tested, which were as follows: chest, triceps, subscapular, axilla, suprailiac, abdominal, and thigh. These sites were then measured three times each, with the average value calculated for analysis.

Once the participants had completed the skinfold measure, the researcher in charge would then measure the stature and mass of each individual. Stature was measured with the use of a tape measure against a wall, while mass was measured using a digital scale. For each measurement, participants were informed to remove any footwear, headwear, and/or any unnecessary clothing.

Station Three: Agility

The third station was designated as the agility station, whereby participants were required to perform the Illinois agility test. The researcher in charge of this station would inform the participants of the requirements of the test (Figure 12). Participants performed the agility test while the researcher recorded the times using a stopwatch. Each participant performed the test three times, with the average time to complete calculated for analysis. Each participant had between three and five minutes of recovery time.

Station Four: Power

The fourth station was designated as the power station. The researcher in charge of this station would inform the participants of the requirements of this station. The power station was comprised of the overhead medicine ball throw (Figure 9), the rotational medicine ball throw (Figure 10), and the standing jump test (Figure 11). Each participant was required to perform each of these tests three times, with the average score calculated for analysis.

STATISTICAL ANALYSES

The statistical analyses used for this study included descriptive statistics, correlation coefficients, independent t-tests, and effect sizes. Mean and standard deviation (SD) values were calculated for each of the variables of interest. Statistical significance was calculated by means of independent t-tests through the STATISTICA 12 software, with a confidence interval of 0.05. Practical significance was portrayed through the use of effect sizes (*z*-score), calculated with the following equation (Coe, 2002):

Effect size = (u15 cohort – u13 cohort) / Sample SD (*eq. 3*)

The sample standard deviation was the standard deviation pooled from both groups. The criteria used for interpreting effect sizes were: a *z*-score of <0.2 was considered trivial, a *z*-score of 0.2 – 0.6 was small, a *z*-score of 0.6 – 1.2 was moderate, a *z*-score of 1.2 – 2.0 was large, and a *z*-score of >2.0 was considered very large (Hopkins, 2004).

STATISTICA 12 was also utilized to calculate correlation coefficients between variables, with a confidence interval of 0.05. The r and r^2 values were graphically displayed to indicate the strength of the relationships between variables.

STUDY II: CONSTRAINTS-LED INTERVENTION

RESEARCH AIM

This study aimed to determine whether a constraints-led batting drill used for training would result in improved development in technical skill of adolescent batsmen. The batting drill focused on the manipulation of the cricket ball to specific areas around the field, opposed to traditional training methods which focus on the interactions between batsman and bowler. Technical skill, in the context of this study, refers to the batsman's capability to execute a cricket stroke to a desired area in the field.

A subsidiary objective of this study was to identify the strengths and weaknesses of adolescent cricket batsmen while participating in the batting skills test. Furthermore, the study aimed to investigate and evaluate the subjective nature of scoring areas by analysing the self-selected scoring zones and the success of hitting those zones, for adolescent cricket batsmen.

STUDY DESIGN

A non-randomized cluster control design was implemented for this study whereby participants from four, well-established cricketing schools in the Eastern Cape province of South Africa were recruited for participation in this study. Recruitment took the form of electronic contact with each respective coach. Participants from the same school were clustered together into either the experimental and control group to alleviate the possibility of cross-contamination of the batting intervention protocol.

A non-randomized selection procedure was decided upon due to logistical reasons, with participants from one school unable to partake in the intervention protocol due to geographical constraints. These participants were therefore assigned to the control group. The three remaining schools in the area were ranked according to results of matches played against one another over the previous five seasons. From this ranking, participants from the first- and third-ranked schools were selected for the experimental group, while participants from the second-ranked school completed the control group. This was done in an attempt to reduce the effect of possible discrepancies between teams (i.e. best and worst case scenarios).

Table 7: Breakdown of schools into experimental and control groups

Experimental	Control
Grahamstown School 1	*Port Elizabeth School*
Grahamstown School 3	*Grahamstown School 2*

PARTICIPANTS

Twenty-four (24) school boy cricketers from four schools in the Eastern Cape province of South Africa were recruited for participation. Six top-order batsmen were selected from each school's under-15 'A' team to participate in the pre- and post-intervention testing procedure. Twelve batsmen (six each from two schools) were assigned to the experimental group with the remaining twelve assigned to the control group. All testing and intervention sessions took place on centre wickets provided by each respective school. Testing was performed during the latter half of the 2014/2015 cricket season (January to March 2015). Ethical approval for human involvement was granted from the Rhodes University Ethics Committee (2013Q4-14), while informed consent was received from each of the participants and their respective parents, coaches, and headmasters (*Appendix B*).

Success in cricket batting is highly dependent on the skill level of individuals, and as such an eligibility criterion was necessary to ensure similarity among participants.

Eligibility criteria

As the focus of the study was on adolescent male cricket batsmen, the main eligibility criterion was that participants were required to be adolescent male cricket players. Cricket batting is a highly skill-dependent movement task; therefore the most essential inclusion factor was that participants were required to be top-order batsmen. This was enforced in an attempt to nullify the variability of skill among participants. For example, there is expected to be a significant difference in skill level when comparing batsmen with bowlers; however when comparing batsmen amongst each other the discrepancies in skill level would not be as severe.

As cricket is a highly skilled sport, with innumerable factors that may influence the level of skill development, it is crucial that participants have a similar level of skill in order to qualify for comparison. Quantifying this characteristic may not be feasible in a short space of time; therefore each participant was required to complete a questionnaire prior to testing that enquired about the level of involvement within cricket (experience), past physical activities and participation in other sports, as well as intrinsic motivation.

The questionnaire attempted to alleviate any major discrepancies between participants, such as the amount of training sessions during the week, the number of years playing cricket, the percentage of those years as a specialized batsman, and so forth. Ideally, participants needed to have been exposed to similar cricketing opportunities for a similar period of time.

It was assumed that participants would be of a similar level of batting skill due to the similarities in team performance between the selected schools. Potential participants were excluded from the study if their cricketing experience and/or motivation to continue playing cricket were substantially different from the norm. For example, a participant who has only one year of cricket playing experience compared with the group norm of six years of experience. Once participants successfully matched all the necessary requirements of the questionnaire, they were assigned to a control or experimental group according to school.

PROTOCOL

Pre-screening questionnaire

A questionnaire (*Appendix D*) was administered to each participant prior to the commencement of the intervention period. This questionnaire served as a pre-screening measure to ensure that participants were matched according to level of cricketing experience. Participants who differed substantially from the norm of the target population were excluded, and replaced with more suitable candidates.

The questionnaire was designed to identify the participants' involvement in cricket, with items pertaining to the length of cricket playing experience, the participation in cricket outside of a school environment, the motivation to excel in cricket, and so forth (see *Appendix D*).

Pre- and post-intervention test

The evaluation measure used to compare differences over time between the control and experimental group was a batting skills test, modified from the novel batting skills test developed by Portus *et al.*, (2010). The batting skills test assesses a batsman's capability to manipulate deliveries to specific targets around the playing field under varying speed and length conditions. The authors noted that the batting skills test aptly distinguished batsmen according to their level of skill, thus confirming the validity of the novel test (see Portus *et al.*, 2010).

This batting skills test was performed by each participant prior to the start of the 2015 cricket season (January: pre-intervention) and after the cessation of the season (March: post-intervention). This occurred at each participant's respective school cricket ground, in place of a normal school practice session. The pre-intervention test (baseline) took place during the first week of the 2015 cricket season, with the post-intervention test performed during the week succeeding the final fixture of the cricket season. This nullified any potential variability that may have been caused by additional training sessions. Participants were discouraged to perform additional training sessions during the intervention period.

Batting skills test (developed by Portus et al., 2010)

The purpose of this test was to quantify the batsman's capability to manipulate the ball around the playing field under varying conditions of speed and length. The objective of the test required batsmen to hit a number of deliveries through specific targets around the field (Figure 13). Each target was assigned a score of '1' or '4', with a greater weight of runs for more accurate strokes. The test allowed researchers to determine each batsman's accuracy of execution according to specific gaps in the field, which is an important skill in order to score runs in cricket.

The difficulty of the test was controlled by means of six conditions, each defined by the speed (110km.h^{-1} or 130km.h^{-1}) and length (full, good or short) of the deliveries. In each condition (i.e. 110km.h^{-1}, good length), batsmen faced seven deliveries with the requirement to hit each delivery through an instructed target area (marked by cones, Figure 13), with runs awarded according to the degree of accuracy of each stroke. This was performed sequentially, from the mid-off position through to the mid-on position (Figure 13). Batsmen were required to face 42 deliveries throughout the batting skills test with the objective to score as many runs as possible.

Four runs were rewarded if batsmen hit the ball through the red cones (4m apart; Figure 13), and one run was awarded if batsmen hit the ball between the red and green cones (1m apart; Figure 13). Zero runs were awarded if batsmen missed the target cones completely, or if the incorrect target cone was hit accidentally. From these runs, statistical inferences could be made with regard to overall accuracy of batsmen as well as specific strengths and weaknesses of batsmen in terms of accuracy according to speed, length and target areas (Portus *et al.,* 2010).

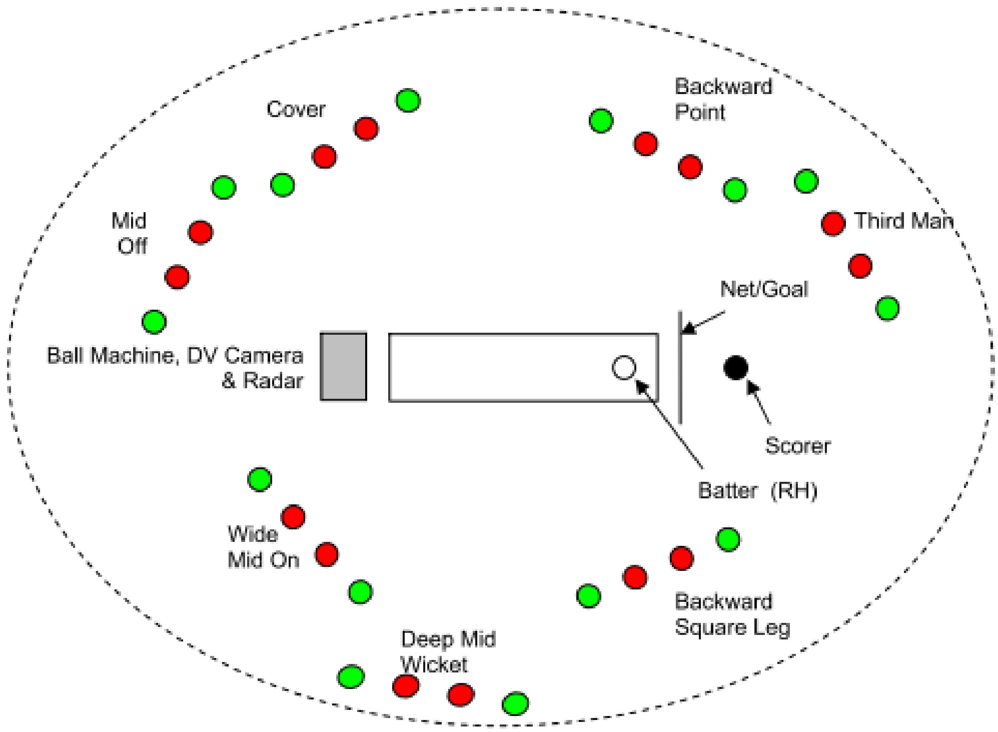

Figure 13: Batting skills test layout for a right handed batter (extracted from Portus *et al*., 2010)

Alterations to the batting skills test

As this study focused on adolescent cricketers, it was important to alter the conditions of the batting skills test to satisfy the sample population. Firstly, the speeds used by Portus *et al*. (2010) were acceptable for the skill level of the participants used during that study; however the ecological validity would be far greater if speeds in this study were more representative of adolescent bowlers. Therefore, speeds were adjusted according to average speeds of under-15 adolescent fast and medium-fast bowlers. With the use of qualitative data obtained from local school cricket coaches, it was agreed that 100km.h^{-1} (± 60 mph) was an acceptable speed to classify under-15 adolescent fast bowlers. Furthermore, the remaining speed of 110km.h^{-1} was reduced to 80km.h^{-1} (± 48 mph) to represent adolescent medium-fast bowling.

Secondly, the design of the target areas was altered so that more weight was given for one run as opposed to four runs. The reason being is that four runs is more difficult to hit during real match settings compared to hitting one run; which is explained by the ratio of runs scored as singles (one run) compared to boundaries (four runs). Therefore the new target areas positioned the red cones two metres apart and the red and green cones two metres apart, for a combined width of six metres (Figure 14). The overall width of the target cones was the same as the original protocol designed by Portus *et al*. (2010). This provided added incentive for batsmen to be accurate in order to score greater runs.

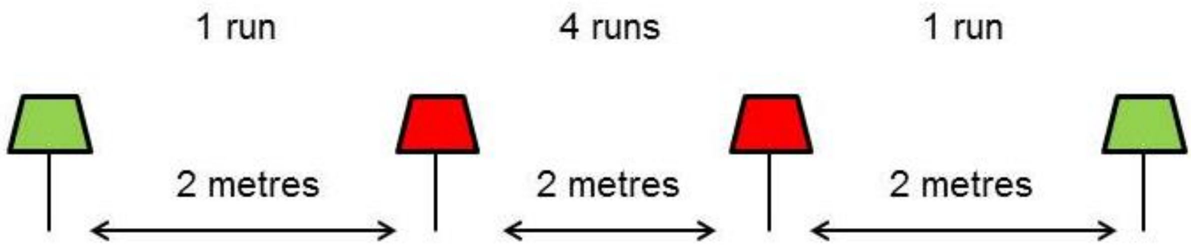

Figure 14: Design layout of the target cones, altered for this study

The third and fourth changes were required due to time constraints within the testing session. Thirdly, the number of conditions was reduced from six to four, with the change occurring by removing one of the lengths. Therefore, only two lengths were utilized in the batting skills test: a full length (± 2.5m from batting crease) which allowed batsmen to play an array of front-foot strokes, and a short length (± 7m from batting crease) that allowed batsmen to play an array of back-foot strokes. Lastly, the number of deliveries was reduced from 42 to 36 balls (six by six-ball overs). This resulted in batsmen being afforded nine deliveries within each condition (speed: length).

Table 8: Breakdown of the study design altered for Study II

TEST	*PRE*				*POST*			
SPEED	*FAST*		*MEDIUM*		*FAST*		*MEDIUM*	
LENGTH	*FULL*	*SHORT*	*FULL*	*SHORT*	*FULL*	*SHORT*	*FULL*	*SHORT*

Along with the implementation of the changes to speed, number of conditions, number of deliveries, and the design of the target areas, a change in the sequence of targets was introduced, with batsmen required to hit the following sequence: (1) mid-on, (2) mid-off, (3) mid-wicket, (4) extra-cover, (5) square-leg, (6) cover-point, (7) fine-leg, and (8) third-man (Figure 15). This altered the target area quite significantly, therefore requiring different cricket strokes for each delivery (i.e. one delivery was driven through the covers; the next was hit on to the leg side). This was employed to avoid hitting similar cricket strokes in succession.

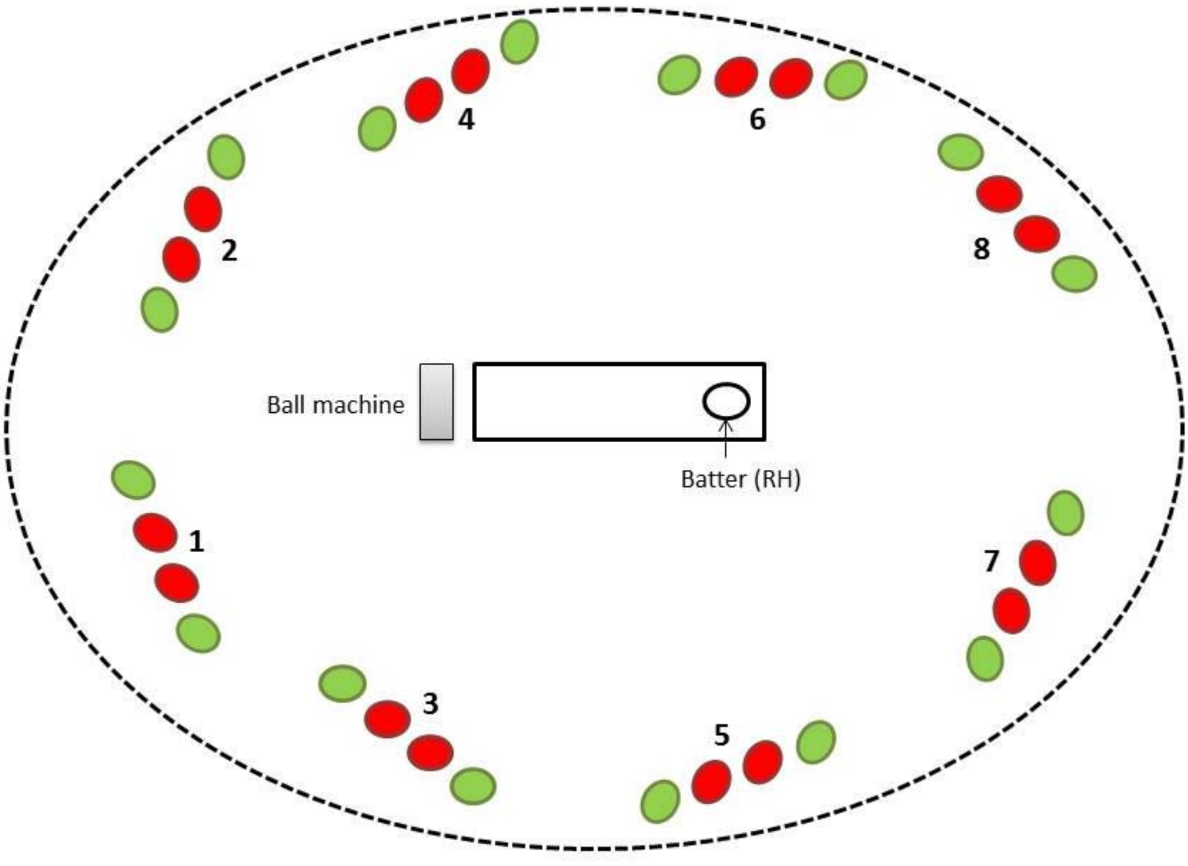

Figure 15: Sequence of target zones for this study

The ninth delivery in each condition was instructed to be hit through a self-selected target zone. This provided the participant with options to hit various target zones according to the line and length of the delivery. Emphasis was placed on the importance of hitting a target zone for the ninth delivery. This inclusion provided the researcher with insight into preferred scoring areas, as well as evaluation on the execution of strokes to preferred scoring areas.

The line of the deliveries across all four conditions was fixed: 10cm outside off-stump. This was decided to reduce the time to alter lines according to speed and length. The ball projection machine was set up to deliver balls from over-the-wicket to right-handers and around-the-wicket to left-handers. Participants were informed to shift their stance guard according to the target area they were required to hit. For example, if the participant was required to hit a delivery through the mid-wicket cones, they were instructed to shift their stance guard across to the off-side to change the line of the delivery towards the body, thus opening up a free leg-side cricket stroke. The target cones were positioned symmetrically on the off- and leg-side to accommodate both right- and left-handed batsmen. This protocol was used for the pre- and post-intervention measurement.

To summarize, participants were required to hit as many targets as possible within each of the four conditions (fast full: FF; fast short: FS; medium full: MF; medium short: MS); each participant received nine deliveries per condition, with eight deliveries required for the eight target zones, and the ninth delivery required to be hit through a self-selected target zone (n = 36 deliveries). The batting skills test was to be performed on a centre-wicket pitch, as would be the case for real match play.

Incremental batting intervention

The twelve batsmen in the experimental group were required to participate in the batting intervention protocol throughout the first half of the 2015 cricket season (January to March). These participants trained for one session per week for the six-week cricket season. Sessions ran parallel with normal school practice schedules (i.e. during normal school practices), therefore not altering the amount of practice that would normally have taken place.

The constraints-led intervention aimed to afford participants an environment representative of a real match situation, with the introduction of fielding constraints during training. The intervention protocol focused on training batsmen to manipulate the ball around the field and hence the objective of the training sessions required batsmen to hit deliveries through specific, selected target areas positioned around the inner ring. The batting protocol was set up on a normal cricket pitch, with a net sealing off the 30-yard circle beyond the target cones.

An incremental training intervention was designed to provide participants with progressive difficulty with each intervention session. The initial intervention session was a simple opportunity for participants to hit targets around the inner field. Over the course of the intervention, each session increased in complexity in order to provide participants with greater challenges than the previous session. Batsmen were encouraged to hit as many deliveries as they could during the intervention training sessions.

Breakdown of the incremental intervention design

Week 1: Pre-intervention test (Baseline measurement)

Batsmen were required to perform the batting skills drill (see *Batting skills test*) in order to establish a baseline measurement for their technical skill. This was performed by the experimental and control groups respectively. Two batsmen performed the test together; one batsman faced deliveries during a condition, while the other batsman collected all the balls around the net. Batsmen would then swap roles for that condition, and this process would be repeated for the remaining three conditions.

Week 2: Introductory session

The first week of intervention training was used as a semi-habituation session, whereby batsmen were afforded the opportunity to understand the nature of the protocol. For the first half of this training session, batsmen were required to play as they would in a normal middle situation, with target cones providing visual representation of the gaps in the field. Live bowlers provided deliveries for batsmen to face, with fielders trying to negate any runs being scored. The number of target cones hit was recorded; however there was no enforcement to hit the target cones. The target cones were placed five metres apart.

Halfway through the batting session, the batting objective was manipulated. Batsmen were required to play as they would in a normal middle situation, with the objective to hit a minimum of a quarter of the deliveries they received through the stipulated target cones. The number of target cones hit was recorded. The main evaluation from this session was the ratio of dot balls to targets hit. Dot balls were defined as any delivery that failed to hit a target. Batsmen were informed that each dismissal would result in a punishable offence (ten "burpees"[3]), prescribed by their respective coach. Batsmen would also be informed of the number of dot balls faced.

Week 3: Introducing task complexities

Batsmen were required to play as they would in a normal middle situation, with the objective to rotate the strike every three deliveries. In order to rotate the strike, batsmen were required to hit deliveries through the stipulated target cones. Each instance a target cone was hit, a different coloured cone would need to be hit for the following target. Target cones alternated colours: mid-off (yellow), extra-cover (orange), cover-point (yellow), third-man (orange), and so forth. As a result, a minimum of 10 deliveries were required to pass through the stipulated target cones, five deliveries through the orange cones and five deliveries through the yellow cones. The number of target cones hit was recorded. The main evaluation from this session was the ratio of dot balls to targets hit. Batsmen would be informed that each dismissal would result in a punishable offence (ten "burpees"), prescribed by their respective coach.

Week 4: Alternating targets

Batsmen were required to manipulate as many deliveries as they could through the various target cones on the off- and leg-side. The target cone width for this week was reduced from five metres apart to four, adding more difficulty to the batting task. Batsmen were encouraged to alternate target cones between off- and leg-side, to avoid hitting to a favoured area. The number of target cones hit was recorded. The

[3] A burpee is a combination of a push-up and a star-jump. An individual is required to complete a push-up, followed by a star-jump (one burpee) without rest. This is continued, without rest, until all burpees are complete.

main evaluation from this session was the ratio of dot balls to targets hit. Batsmen were informed that each dismissal would result in a punishable offence (ten “burpees”), prescribed by their respective coach.

Week 5: Incentivising batting

Batsmen were required to play as they would in a normal middle situation, with the objective to hit as many deliveries through the target cones as possible. Batsmen were incentivised to bat for longer periods by being rewarded for hitting target cones. If batsmen failed to hit a target in the two deliveries received, they would rotate strike with their batting partner; if the batsmen hit a target, they would remain on strike for a further two deliveries. Batsmen were only able to run singles once the ball had passed through a stipulated target cone. The number of target cones hit was recorded. The main evaluation from this session was the ratio of dot balls to targets hit. Batsmen were informed that each dismissal would result in a punishable offence (ten “burpees”), prescribed by their respective coach.

Week 6: Post-intervention test (Comparative measurement)

An identical procedure to the pre-intervention test measurement in *Week 1* was used. The technical ability of batsmen was reassessed by means of a batting skills drill. This was performed by the experimental and control groups respectively.

The design of the intervention sessions attempted to replicate a traditional school boy cricket practice in terms of the amount of deliveries received for each participant. There was no significant difference in the number of deliveries faced for the experimental group during each session compared to a normal school practice (the control group). Therefore, neither the experimental nor the control group trained for a significantly greater period than their current training procedures, eradicating the possibility of improved performance due to additional training.

MATERIALS AND EQUIPMENT

The pre- and post-intervention batting skills test made use of a Brell Express Bowling Machine (Flicx, South Africa) and Brell yellow plastic bowling balls (n = 18). A Radar Speed gun (SR3600, Sports Radar LTD, Homosassa, USA) was used to control for the speed of the bowling machine across testing sessions. The testing and intervention sessions took place on a traditional cricket field, with a cricket net (1 metre x 170 metres) closing off the 30-yard circle. The function of the cricket net was to collect balls that had been hit around the inner ring. The net was supported by 34 iron rods (rebar), each embedded five metres apart. The net was held up by makeshift hooks, made out of curtain hooks and cable ties. The target areas were made up of two different coloured plastic cones (see Figure 15). Each target area required four plastic cones; therefore the eight target areas required a total of 16 green plastic cones and 16 red plastic cones. Each participant used full personal protective cricket equipment, as used in normal training sessions.

Figure 16: Design of the pre- and post-test protocol setup; image showing ball projection machine, radar gun, mid-off and extra-cover target zones

MEASUREMENTS

The objective of the batting intervention protocol was to improve batsmen's capability to manipulate the ball around the field. This level of skill was measured by a number of objective measures (Table 9). Participant's subjective rating of performance was collected to gauge individual performance in association with the objective performance. The result of the subjective rating has not been reported in this thesis.

Table 9: All measures recorded during each training session

Objective measures	Subjective measures
Number of targets hit (Overall)	*Perceived rating of performance*
Runs allocated according to accuracy of target hit (4 or 1)	
Scoring strokes ratio	
Strike rate (%)	
9th ball success ratio	

The same scoring system that was used in the study by Portus *et al*. (2010) was utilized for each session (testing or intervention) in the batting protocol (*Appendix D)*. This allowed for greater categorization of accuracy scores after each session. Rather than having a positive score for hitting the target, participants were given either four runs or one run depending on the degree of accuracy of the stroke to the centre of the target cones. Therefore, the greater number of runs recorded at the end of the session resulted from a greater accuracy to hit the target areas.

Further results included the percentage of individual target areas hit/missed (i.e. target area: extra cover), thereby giving feedback on possible strengths and weaknesses of batsmen's cricket stroke skills. This was interpreted along with the conditions, allowing inferences to be made of accuracy according to speed, length and target area.

The number of errors made by batsmen was also recorded, indicated by missed targets and missed deliveries. Subjective measures of batsmen's 'form' were recorded by means of a questionnaire designed specifically for this study (*Appendix D*). The questionnaire enquired about the batsman's stroke play, including quality of bat-ball contact and subjective evaluation. The subjective evaluation was based on bat-ball contact and not on accuracy of manipulation. This provided subjective evidence to match that of the objective results recorded, therefore gaining an idea of how batsmen perceived their own training sessions in conjunction with how well they had done statistically. The results of the subjective rating of performance were not recorded for analysis in the thesis.

PROCEDURE

Pre- and post-intervention testing sessions

Each pre- and post-intervention testing session began with explicit verbal instructions of what was required of each participant. This included the breakdown of the objective of the batting skills drill, as well as the scoring system of the target areas and the sequence in which the participants were required to hit each target area.

Participants were reminded that the line of the deliveries would be fixed, and that in order to hit cricket strokes through each of the target areas they would need to alter their stance guard accordingly. Participants were told that the scorer would be positioned behind them and provide verbal reminders as to which target area was to be hit next. A research assistant was responsible for feeding deliveries into the ball projection machine.

Participants paired up and batted together during the pre- and post-intervention tests, with one participant facing balls from the bowling machine while the other participant collected the balls around the enclosed net. Each participant faced nine deliveries from one condition, before swapping roles with their batting partner. Before the start of each condition, the participants were informed of the length and speed of the condition. Once the pair had each faced a condition (i.e. fast full), the next condition would be setup by the research assistant. This procedure was repeated for the four conditions, with each participant facing nine deliveries within each condition for a total of 36 deliveries.

If a projected ball could not be hit through a specific target area due to the random variation of the line and length of the delivery (see *Limitations*, Chapter IV), the scorer and assistant would agree that the delivery be retaken. For example, if a participant was required to hit a delivery through square-leg and the delivery projected from the ball machine was full and wide outside off-stump, the scorer and assistant would deem that the delivery was not possible to hit through the stipulated target area. Therefore, the participant would be informed that the delivery would be retaken and that the same target area was to be hit.

The permutation of the conditions altered for each of the batting pairs in order to alleviate the possible discrepancies of results due to learning or exposure effects. Batting pair one would work with the condition permutation A, while batting pair two would work with the condition permutation B, and so forth. Permutation A had the following condition sequence: fast full, medium full, medium short, and fast short. Permutation B followed the opposite condition sequence: fast short, medium short, medium full, and fast full. This allowed the setup of each condition to be performed quickly, wasting little time during the testing session as only one aspect of the condition needed to be altered (i.e. either speed or length).

STATISTICAL ANALYSES

Analysis of variance (ANOVA)

The results of this study were mined through the use of repeated measures and one way ANOVAs. The ANOVAs would provide a test for significance, as well as interaction effects within the conditions. The statistical software, STATISTICA 12, would be utilized to analyse processed data. A post-hoc analysis using the Fisher LSD function was used to assess where differences occurred between the variables. Further analysis of the pre- and post-intervention data was performed to establish an understanding of each group's performance in relation to the four conditions of the batting skills test.

Chi-squared test

It was expected that the distribution of deliveries according to score would differ within and between conditions and tests. The chi-squared tests provide an indication of the distribution of scoring within each condition. Due to the complexity of the task, it was expected that a greater number of deliveries would score a miss (0) compared to deliveries that resulted in hits (1, 4). To prove this hypothesis, a chi-squared *test* analysis was used to interpret the results of the testing procedures.

The following results have been analysed for an understanding of the breakdown between hits (1, 4) and misses (0) within each condition for the pre- and post-intervention tests. Due to the nature of the batting task, a pre-set percentage breakdown of outcomes (0, 1, and 4) was determined according to the probability of success:

- Miss (0): 70%   Hit (1): 20%   Hit (4): 10%

Therefore, the chi-squared test assumed a ratio of 7:3 of misses to hits. As the target zone for 1 was twice as large as the zone for 4, it was assumed that 1 would score twice as much as 4. An alpha value (p) of 0.05 was utilized to determine level of significance.

Descriptive statistics

The descriptive statistics that were utilized in the analysis of the results would provide a visual representation of the performance of individuals according to the targets hit and runs scored during each of the four conditions. These results were recorded as mean and standard deviation (SD), unless otherwise stated.

CHAPTER IV

RESULTS

STUDY I: PROFILING DATABASE

Study characteristics

A total of 90 (u13: n = 40, age: 12.38 ± 0.67; u15: n = 50, age: 14.86 ± 0.35) adolescent cricket players participated in the profiling database. Results have been presented as mean and standard deviation (SD), unless otherwise stated. Effect sizes have been included to show practical significance. Statistical significance was established using independent t-tests (*Appendix E*).

Anthropometry

Table 10: Mean (± SD) stature and mass measures of adolescent cricket players

Age	Stature (mm)	Mass (kg)
u13	1561 (±95)	51.2 (±14.8)
u15	1725 (±74)	61.6 (±8.9)

U15 adolescent cricket players were significantly taller (± 164 mm, p < 0.0001) and heavier (± 10.4 kg, p < 0.0001) than u13 players (Table 10). Number of participants in each position: ALL (n = 37), BAT (n = 17), BOWL (n = 28), KEEP (n = 8).

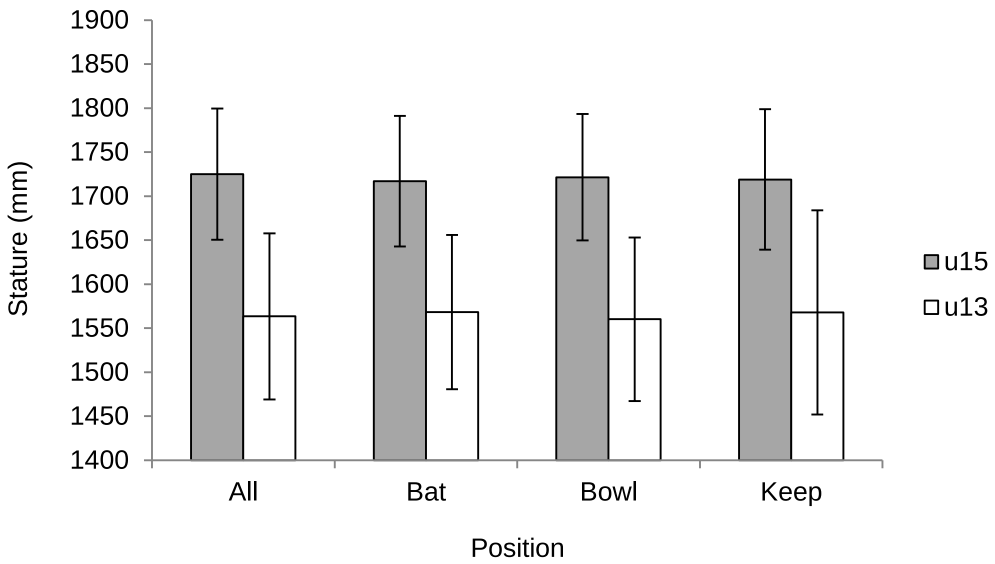

Figure 17: Mean (± SD) stature according to playing position

Stature and body mass were similar across all playing positions, within each age group (Figures 17 and 18).

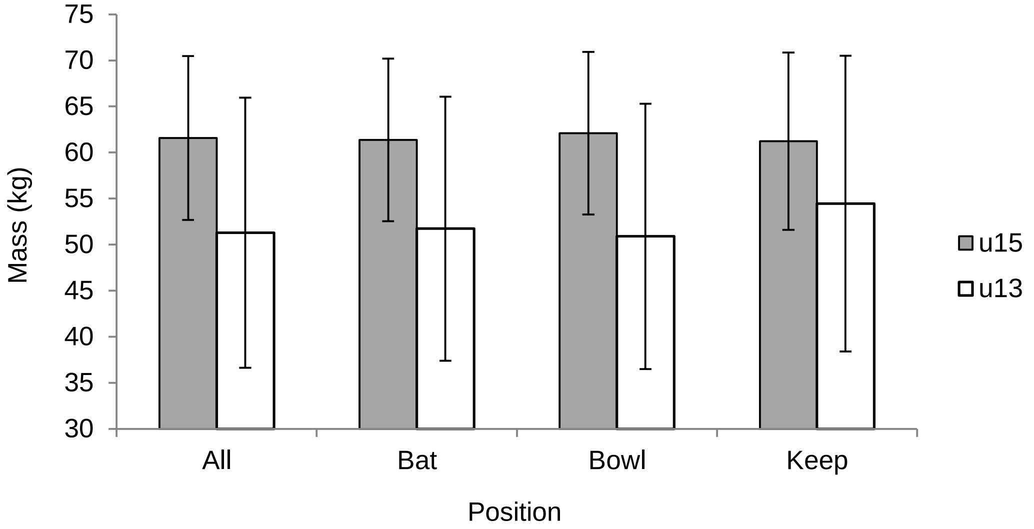

Figure 18: Mean (± SD) mass according to playing position

The analysis of mass and stature according to month of birth suggest little difference, particularly in the u15 age group (Figures 19 and 20). The u13 age group revealed more variance, yet no indication of significance.

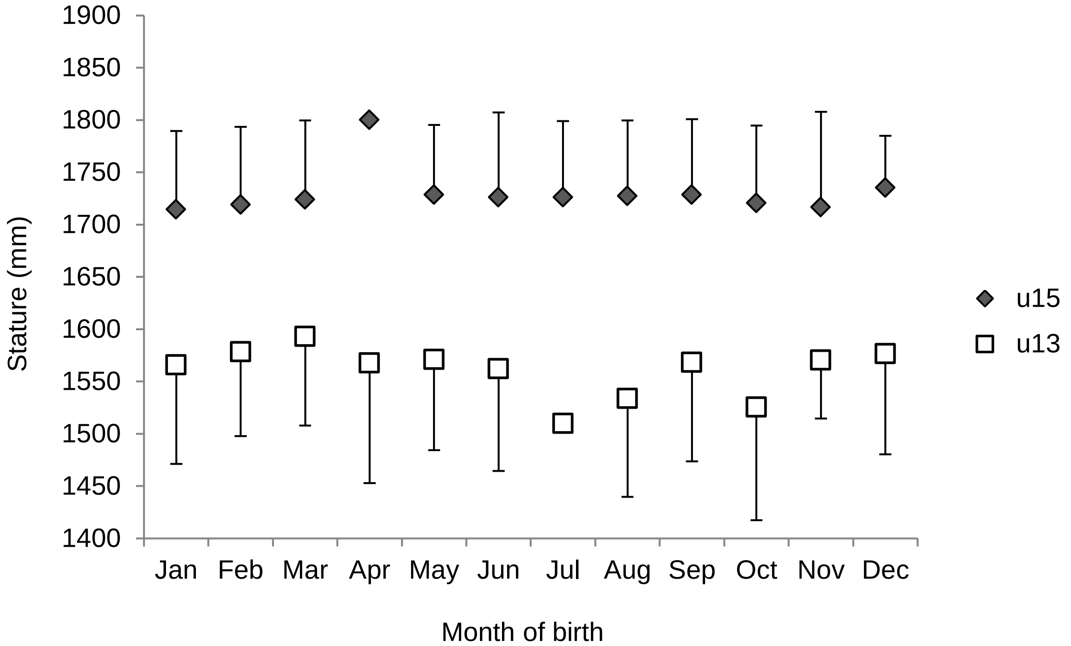

Figure 19: Mean (± SD) stature according to month of birth

(NOTE: There was only one player born in April in the u15 cohort and July in the u13 cohort)

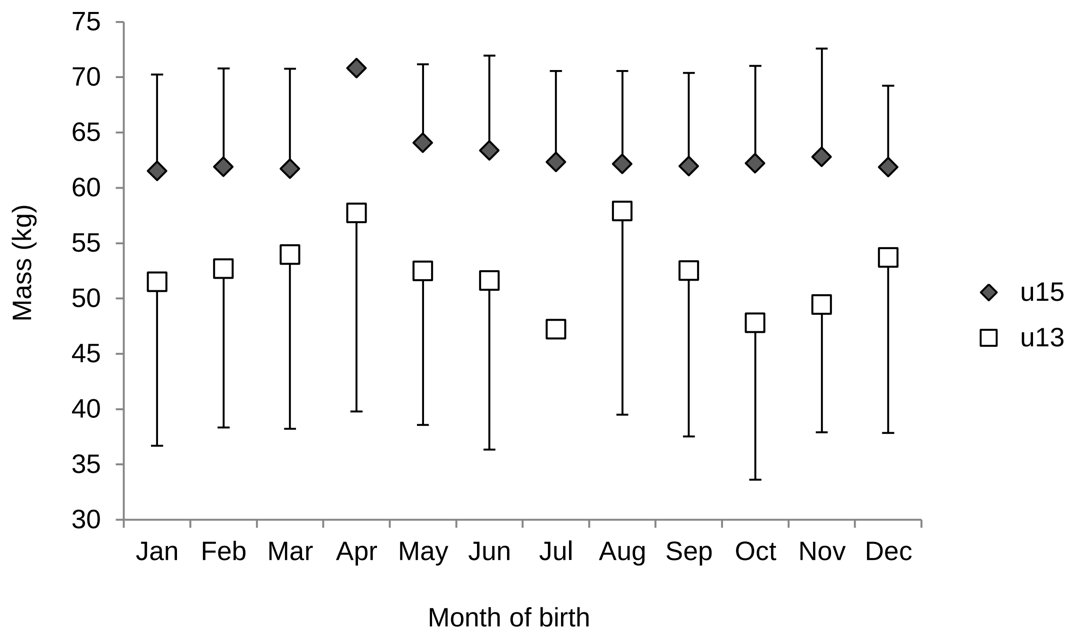

Figure 20: Mean (± SD) mass according to month of birth

This analysis presented a similar pattern between stature and mass for each corresponding month (Figures 19 and 20). There was a greater variance in mass compared to stature. Participant numbers for each month: Jan (n = 8), Feb (n = 9), Mar (n = 10), Apr (n = 4), May (n = 10), Jun (n = 9), Jul (n = 10), Aug (n = 4), Sep (n = 12), Oct (n = 5), Nov (n = 4), and Dec (n = 5).

Table 11: Mean (± SD) limb length measures (mm)

Age	Upper arm	Lower arm	Upper leg	Lower leg
u13	289 (±26)	234 (±18)	385 (±34)	379 (±25)
u15	312 (±27)	263 (±16)	422 (±27)	415 (±23)

The u15 age group recorded significantly ($p < 0.0001$ each) greater values across each of the four limb measurements (Table 11). The upper arm and upper leg were greater in length compared to the lower arm and lower leg respectively, within each age group. The effect sizes of the limb lengths of the u15 age group were 0.85 (upper arm), 1.32 (lower arm), 1.07 (upper leg), and 1.22 (lower leg).

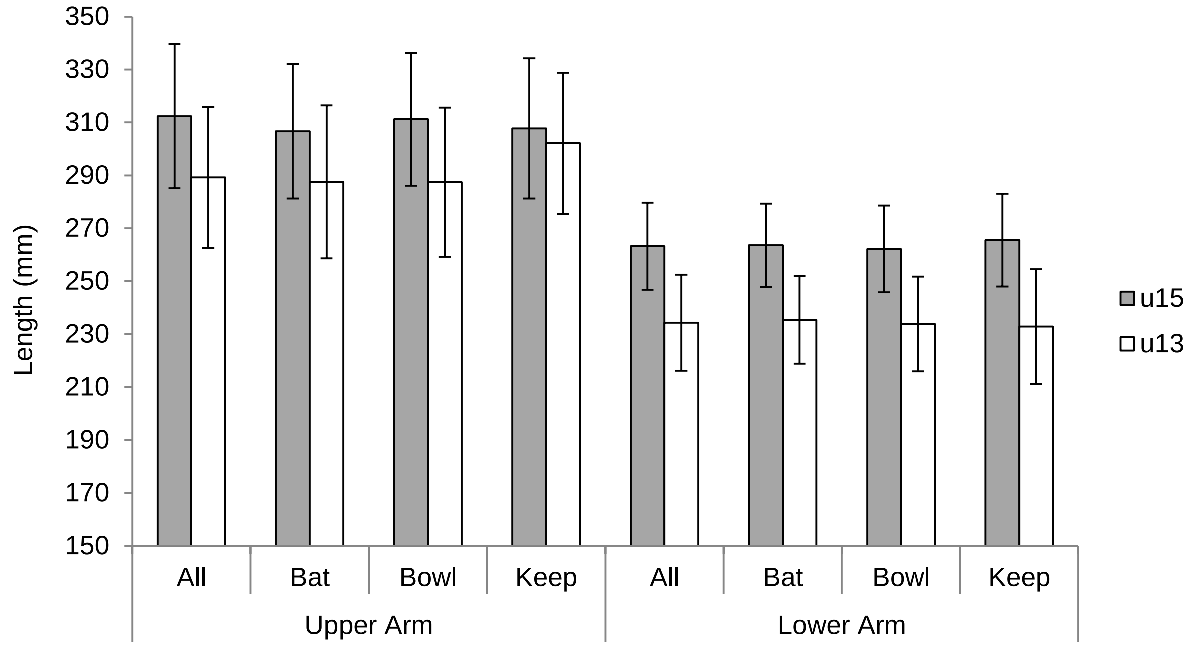

Figure 21: Mean (± SD) upper limb anthropometry according to playing position

There were no significant differences (upper arm: $p < 0.3953$; lower arm: $p < 0.3133$; upper leg: $p < 0.8839$; lower leg: $p < 0.7704$) in limb lengths between either age group and for each of the four primary playing positions (Figures 21 and 22).

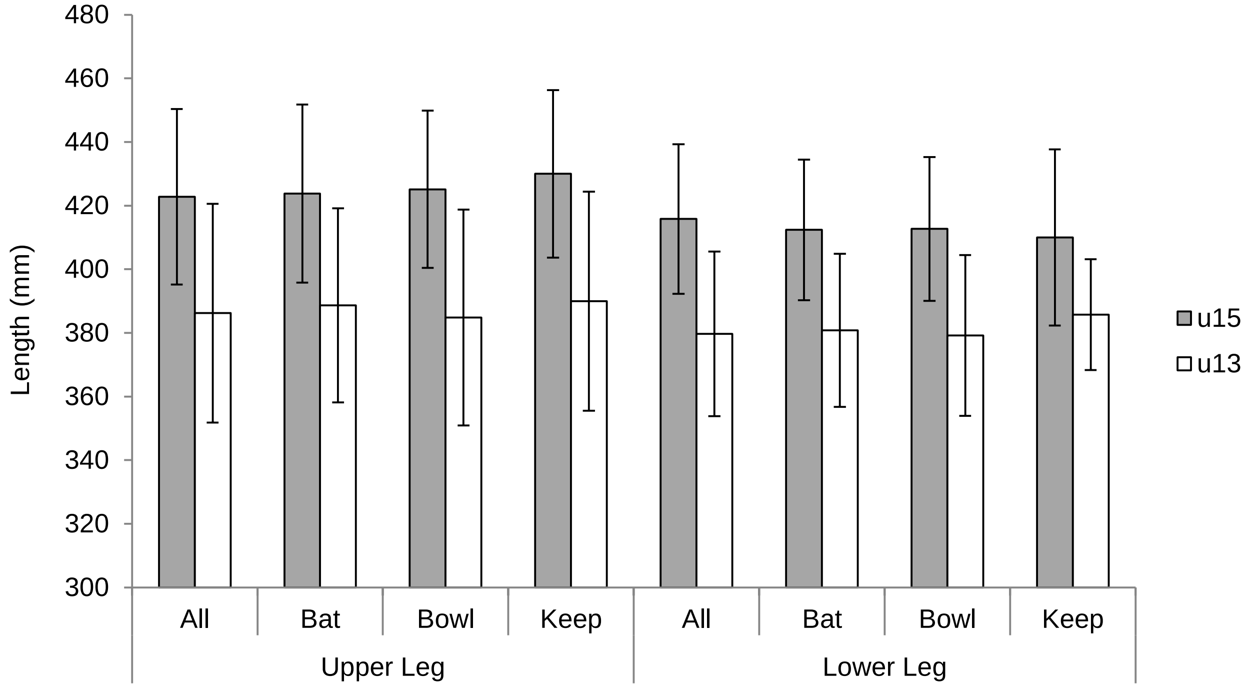

Figure 22: Mean (± SD) lower limb anthropometry according to playing position

Morphology

Table 12: Mean (± SD) body composition of adolescent cricket players

Age	BMI (kg/m^2)	Body density (g/cc)	Body fat (%)
u13	20.65 (±0.04)	1.07 (±0.01)	10.25 (±5.45)
u15	20.68 (±0.03)	1.08 (±0.01)	7.41 (±3.88)

Body mass index (BMI) measures were similar between the two age groups. The u13 age group had significantly ($p < 0.0049$) greater body density and body fat percentage ($p < 0.0049$) compared with the u15 age group (Table 12). The effect sizes of body composition were: 0.01 for BMI (u15), 0.59 for body density (u15), and 0.59 for body fat percentage (u13).

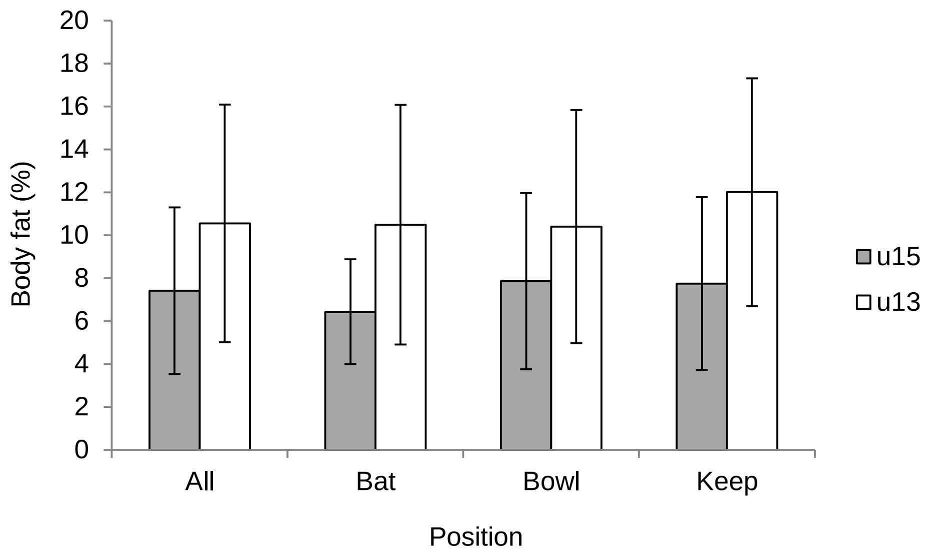

Figure 23: Mean (± SD) of body fat percentage across the playing positions

There were no differences in body fat between playing positions, within each age group (Figure 23). The effect sizes for each of the playing positions were: 0.65 for all-rounders (u13), 0.54 for batsmen (u13), 0.52 for bowlers (u13), and 0.88 for wicket-keepers (u13).

Flexibility

Table 13: Mean (± SD) flexibility (mm) of adolescent cricket players

Age	Trunk	Shoulder	Hamstring
u13	238 (±64)	442 (±151)	68 (±58)
u15	207 (±64)	404 (±102)	43 (±79)

The u13 age group recorded significantly ($p < 0.0295$) greater trunk extension compared with the u15 age group. No differences were noted for shoulder extension and hamstring flexibility (Table 13). The effect sizes for flexibility measures were 0.46 for trunk extension (u13), 0.27 for shoulder extension (u13), and 0.37 for hamstring flexibility (u13).

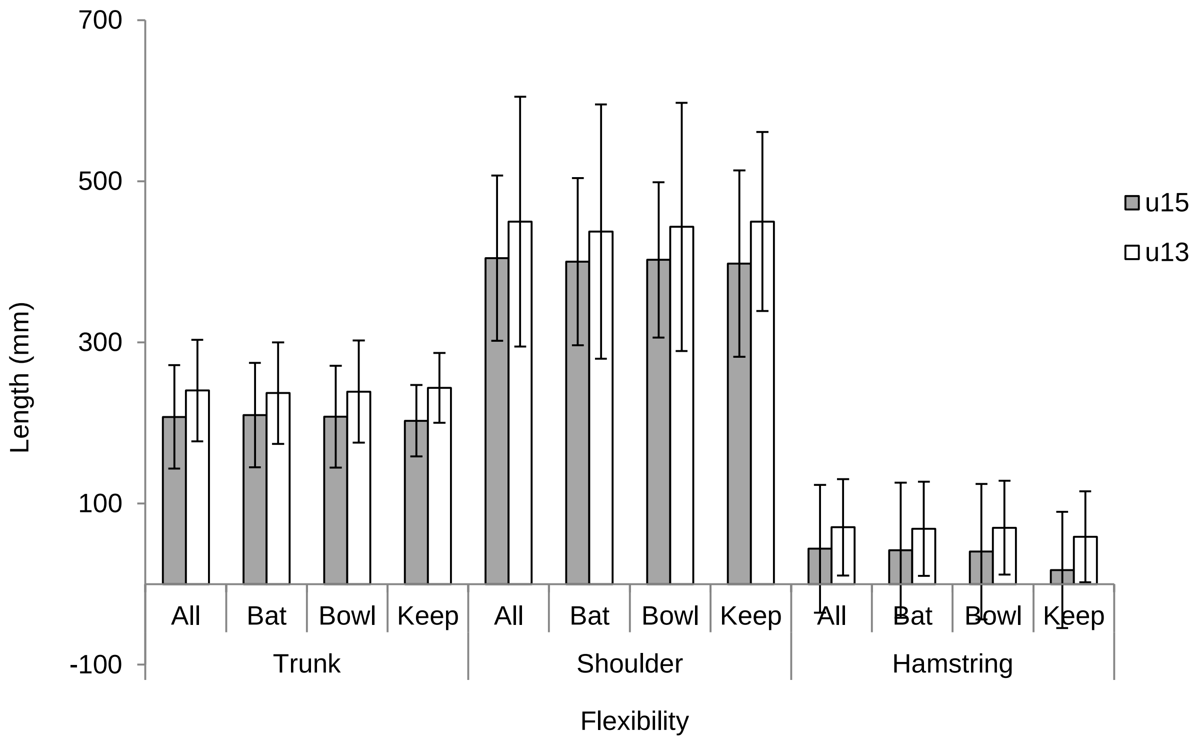

Figure 24: Breakdown of flexibility measures according to playing position

There were no differences in flexibility measures across playing positions, within each age group (Figure 24). Negative standard deviations for hamstring flexibility (u15) was due to the design of the sit and reach board.

Physical performance

Table 14: Mean (± SD) jumped and thrown distances (cm) of adolescent cricket players

Age	Standing jump	Overhead throw	Rotational throw: left	Rotational throw: right
u13	165.3 (±23.8)	461.7 (±94.8)	522.3 (±153.4)	517.6 (±163.9)
u15	198.9 (±19.3)	630.7 (±107.1)	792.4 (±174.9)	769.3 (±174.7)

The u15 age group recorded significantly ($p < 0.0001$ each) higher scores for each of the four physical strength measures in comparison with the u13 age group (Table 14). The effect sizes for the power measures were 1.24 for standing jump (u15), 1.31 for overhead throw (u15), 1.26 for rotational throw: left (u15), and 1.21 for rotational throw: right (u15).

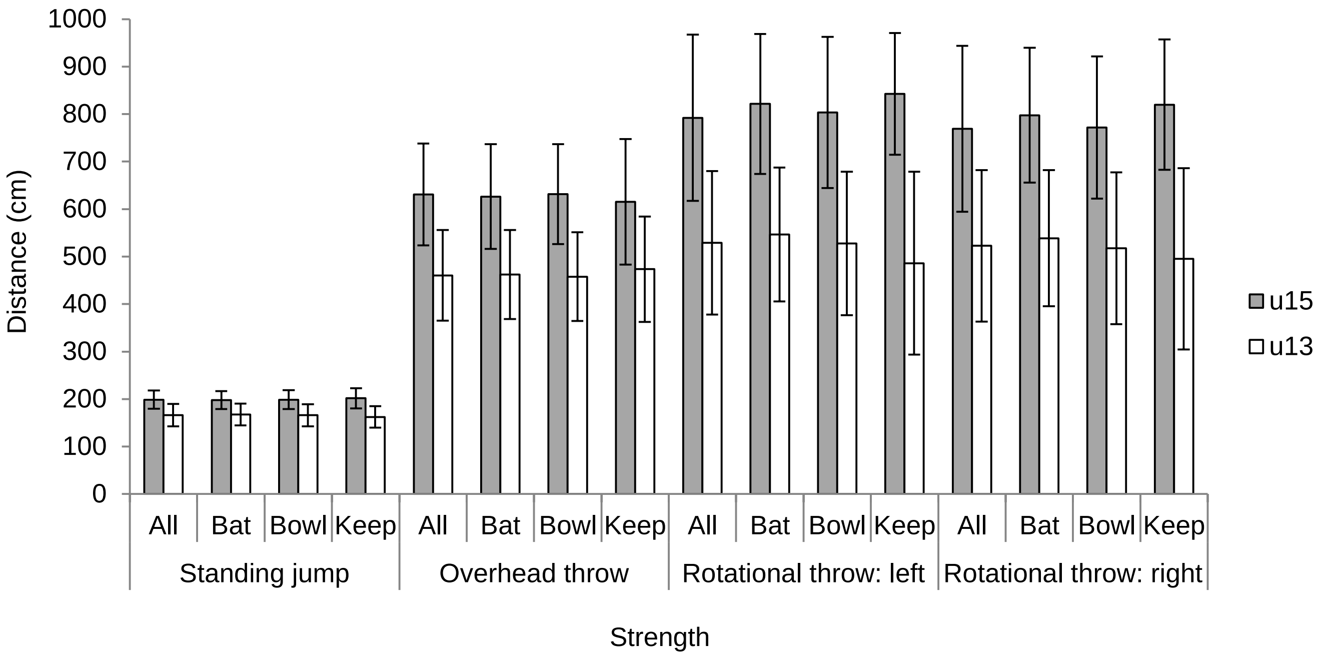

Figure 25: Breakdown of physical performances according to playing position

There were no differences in strength between playing positions, in each age group (Figure 25).

Table 15: Mean (± SD) sprint time (s) for the Illinois agility test

Age	Agility
u13	18.84 (±1.41)
u15	17.24 (±1.65)

The u15 age group recorded significantly ($p < 0.0001$) faster sprint times for the agility test in comparison with the u13 age group (Table 15). The effect size of agility time was 0.92 (u13), indicating a moderate practical significance.

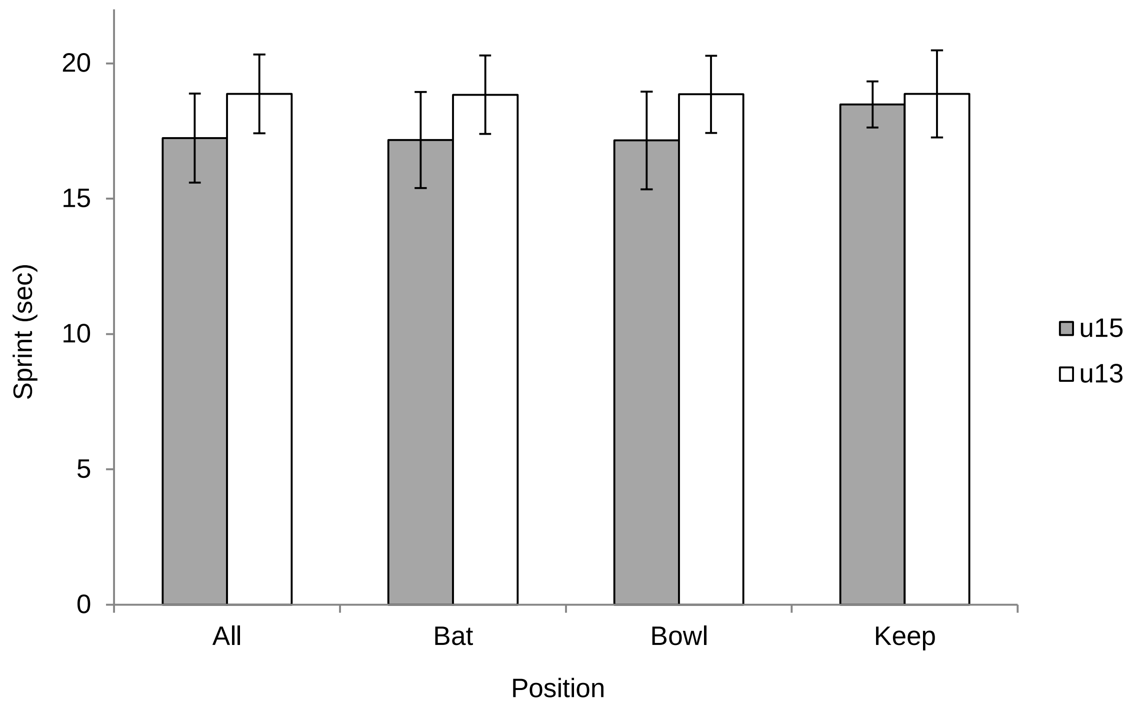

Figure 26: Breakdown of agility time according to playing position

There were no significant differences in agility sprint time across the four playing positions (Figure 26).

Correlations

A Pearson correlation matrix was calculated to assess the relationships across all variables (*Appendix E*). Expected correlations included group with stature ($r = 0.72$), stature with mass ($r = 0.68$), stature with limb lengths (upper arm: $r = 0.67$; lower arm: $r = 0.80$; upper leg: $r = 0.72$; lower leg: $r = 0.74$), mass with BMI ($r = 0.79$), and mass with body fat percentage ($r = 0.47$). There were no significant correlations for either playing position or month of birth effects for any of the variables.

The following figures have been used to graphically represent the strength of the relationship between some of the unexpected correlations found within the flexibility and physical performance variables within each age group (line or regression and r^2 values included).

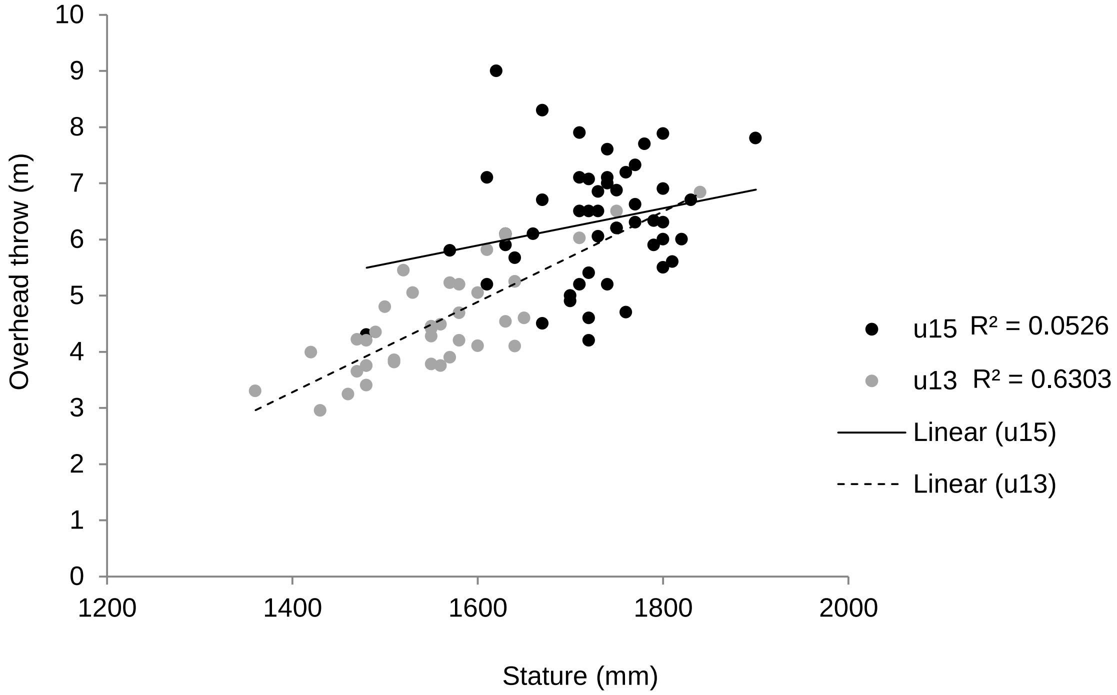

Figure 27: Relationship between stature and overhead throw (r = 0.72) for each age group

Stature had a strong correlation with overhead throw ($p < 0.000000$), with taller participants able to throw the medicine ball further (Figure 27). The u13 age group had a stronger correlation between stature and overhead throw compared with the u15 age group.

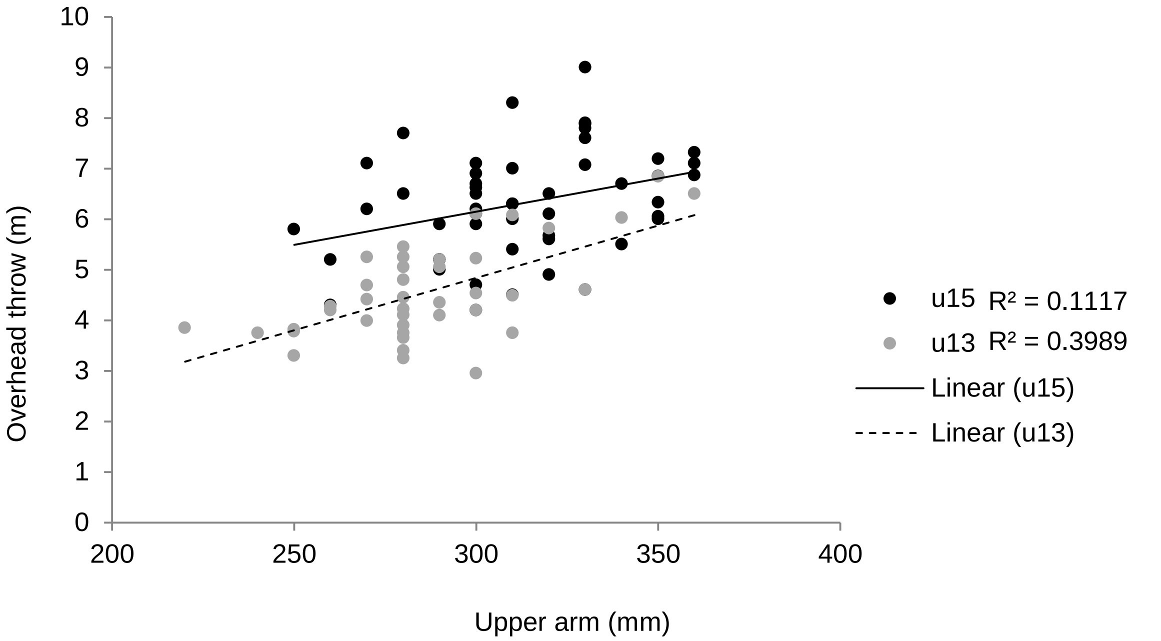

Figure 28: Relationship between upper arm length and overhead throw (r = 0.59) for each age group

The upper ($p < 0.000015$) and lower arm lengths ($p < 0.000006$) correlated with overhead throw performance (Figures 28 and 29). As with Figure 27, the u13 age group had a stronger correlation between upper arm length and overhead throw performance compared to the u15 age group.

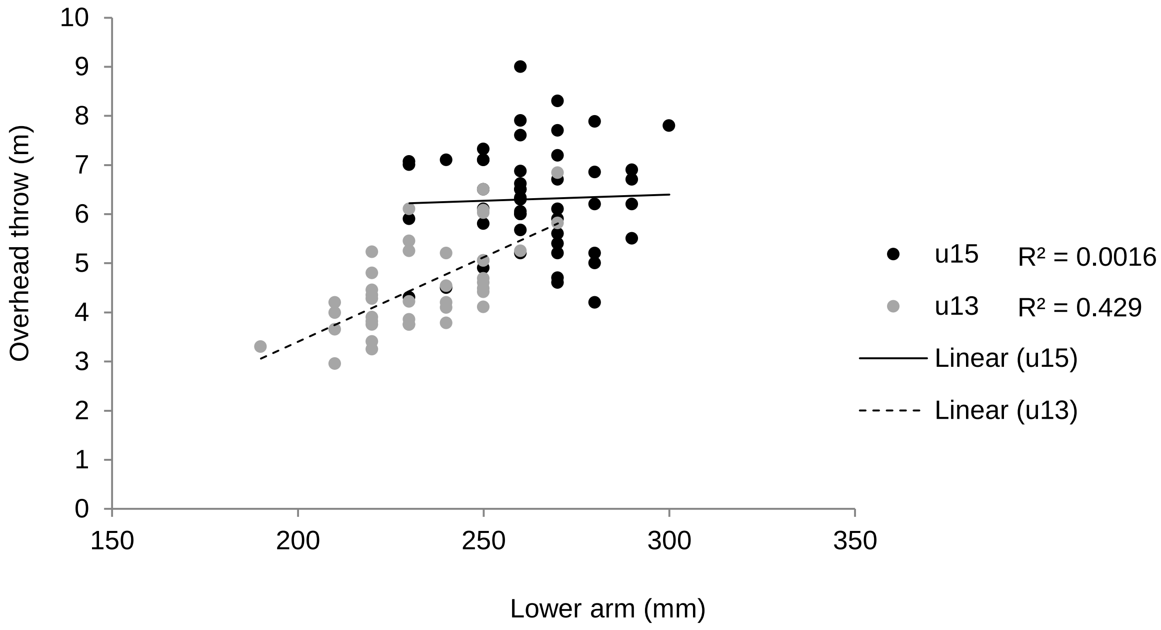

Figure 29: Relationship between lower arm length and overhead throw (r = 0.60)

The u13 age group had a stronger correlation between lower arm length and overhead throw compared to the u15 age group. The u15 age group had a weak correlation between lower arm length and overhead throw (Figure 29).

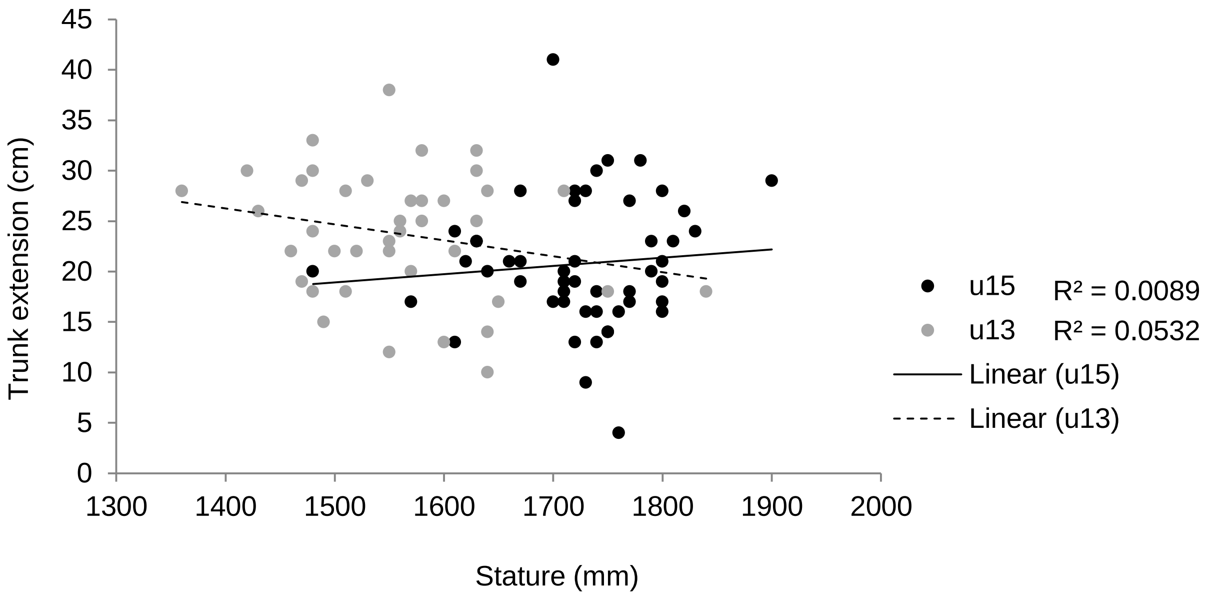

Figure 30: Relationship between stature and trunk extension (r = 0.22) for each age group

Figure 30 shows that the u13 age group had a marginally stronger, yet negative correlation between stature and trunk extension in comparison with the u15 age group ($p < 0.049$). The u15 age group had a positive (albeit weak) correlation between stature and trunk extension.

Figure 31 shows a strong, yet negative relationship between agility sprint time and standing jump for the u13 age group ($p < 0.000000$). The u15 age group showed a weak correlation between agility sprint time and standing jump.

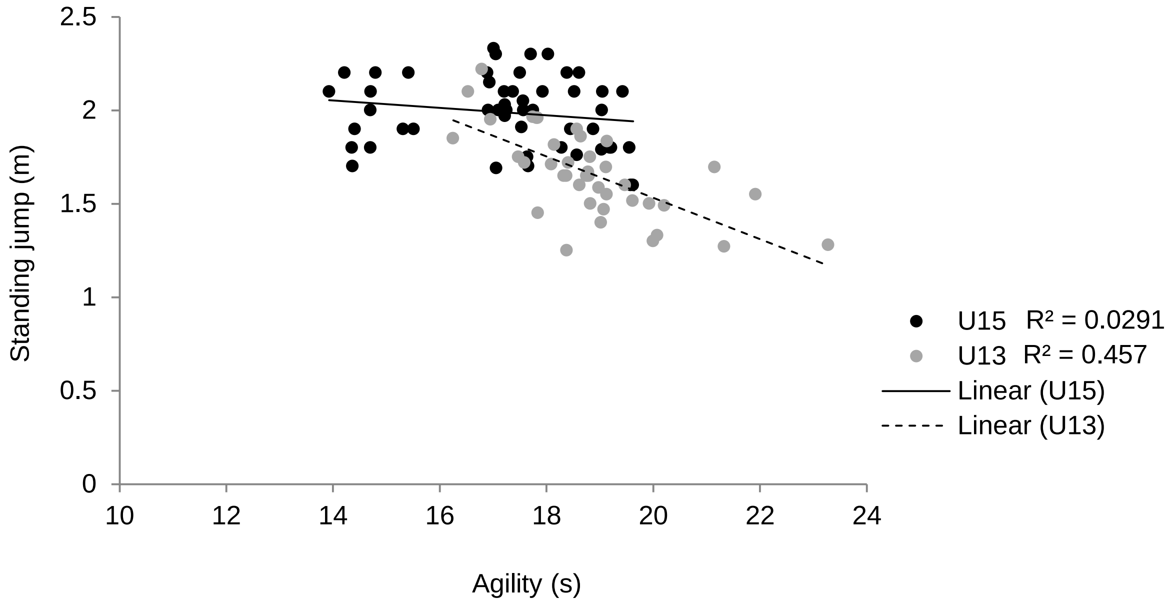

Figure 31: Relationship between standing jump and agility (r = 0.55) for each age group

The u13 age group had a stronger, yet negative correlation between body fat percentage and standing jump performance ($p < 0.000000$). The u15 age group indicated a similar trend, to less a degree.

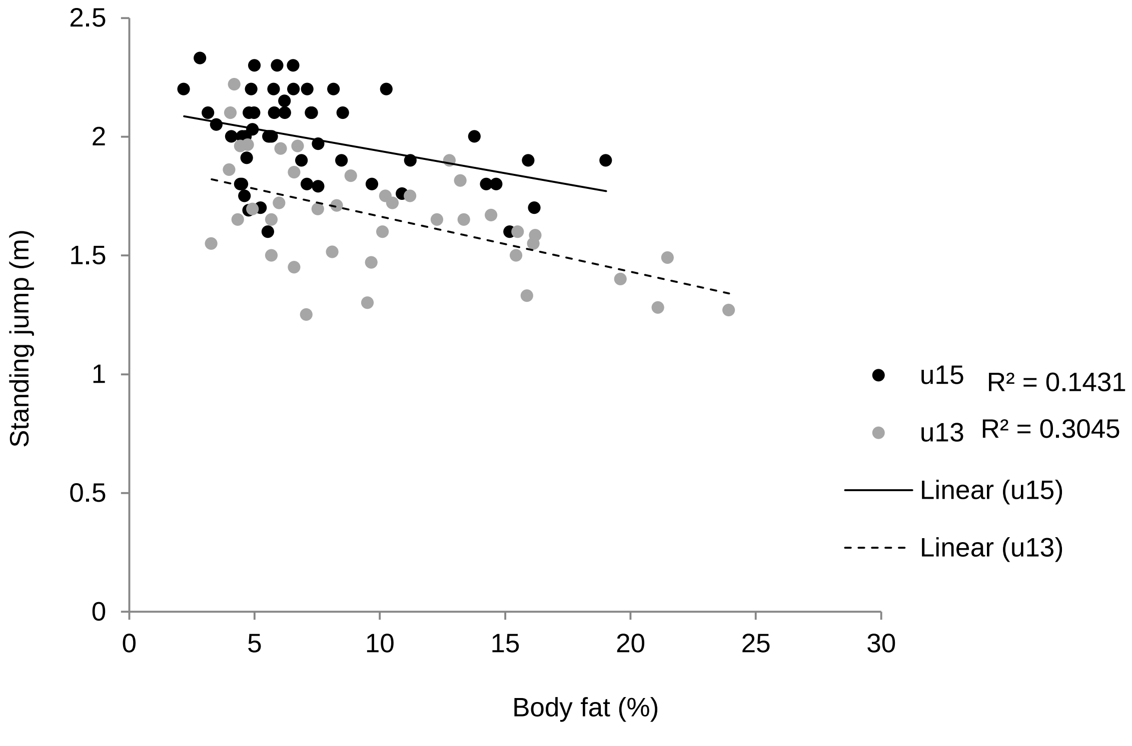

Figure 32: Relationship between body fat percentage and standing jump (r = 0.54)

STUDY II: CONSTRAINTS-LED INTERVENTION

Study characteristics

A total of 23 adolescent (age: 14.63 ± 0.45; left-handed: 1, right-handed: 22) cricket batsmen performed the baseline testing procedure (PRE). One participant from the control group opted out of the study before the study commenced. Each participant was quasi-randomly assigned to the experimental (EXP; n = 12) or control (CON; n = 11) group. Participants from the same school were clustered together to alleviate possibilities of cross-contamination of the training procedure.

Table 16: Summary of adolescent summer sport activity and previous cricket experience

	Days of sport/week	>2 summer sports	External cricket experience	Private coaching
n	4 – 5	16 (70%)	18 (78%)	18 (78%)

The population averaged between four and five days a week participating in sporting activity, with 70% (n = 16) of the sample participating in two or more summer sports. On average, the sample had been playing cricket for more than five years. Of the initial sample, 78% (n = 18) had experience playing cricket outside of a school environment (i.e. Club, Provincial, or National). Furthermore, 78% (n = 18) of the population had received some level of private coaching, ranging from four months to ten years, with the majority participating in private coaching for between two and four years.

Intervention alterations and dropouts

As is the nature of intervention testing, the original six-week batting intervention was reduced by half due to time constraints within the cricket season. Firstly, the South African summer extends from October to March, with the school summer holidays separating the school cricket season into two smaller seasons. This translates to two six-week cricket seasons per annum. Secondly, the pre- and post-intervention tests were scheduled for the first (week one) and last week (week six) of the cricket season. The remaining four weeks were scheduled for intervention training. Lastly, one week of testing was lost due to weather, resulting in a loss of one training session per group.

Thus, the experimental group participated in a three-week batting intervention, with one session of intervention training and one traditional net practice a week. The control group resumed traditional net practices twice a week.

As expected, participation dropout is a common occurrence when performing intervention testing. One school dropped out for the post-intervention testing (CON: n = 5), while a further two participants, one from each group, dropped out for the post-intervention testing session. Therefore, the post-intervention testing procedure was performed by 16 participants (EXP: n = 11; CON: n = 5). As such, the data collected and analysed should be interpreted with care.

Data mining

The results were mined through the use of a repeated measures analysis of variance (ANOVA), chi-squared tests, and with the aid of descriptive statistics. The data is presented as mean and standard deviation (SD), unless otherwise stated. The following results have been structured to provide clear evidence for (*i*) the efficacy of the intervention, (*ii*) the strengths and weaknesses of adolescent batsmen during the batting skills test, and (*iii*) the self-selected performance response and accuracy of adolescent cricket batsmen.

Intervention efficacy

To summarise, the intervention did not reveal any differences in performances between the two groups. The only differences noted in performance were as a combined group during the post-intervention testing procedure. Here, participants scored more runs during the slower speed conditions in comparison with the faster speed conditions. Within speed, the participants scored more runs when facing the shorter length deliveries in comparison with the fuller length deliveries. This should be interpreted with caution due to the large dropout rate from pre- to post-intervention testing sessions.

An intra-class correlation analysis revealed a strong correlation (r = 0.95) between pre- and post-test measures, indicating a strong reliability between test measures.

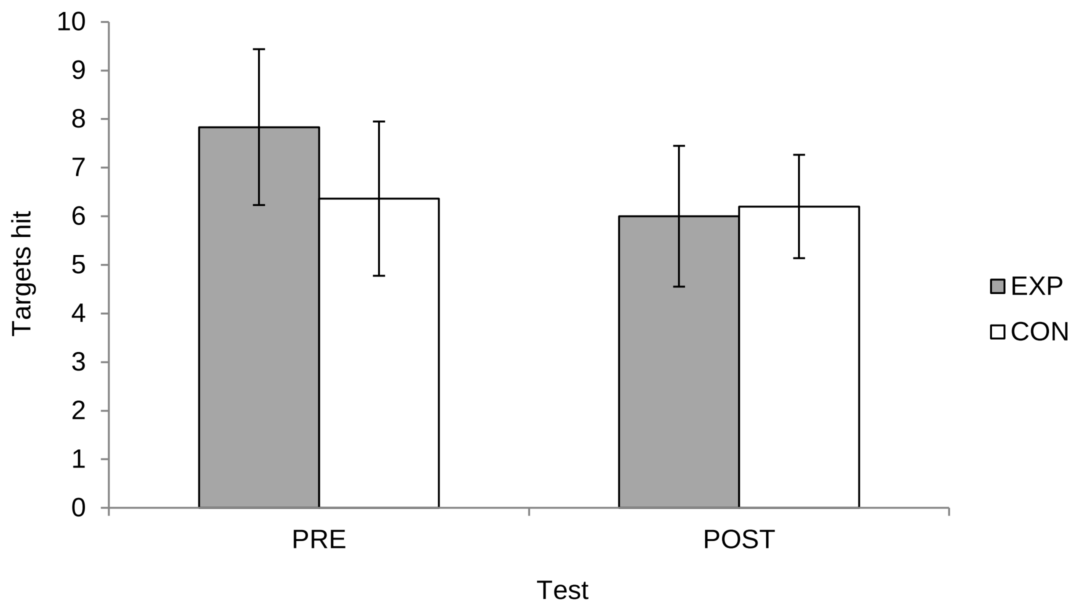

Figure 33: Targets hit for experimental and control groups, across the pre- and post-intervention tests (mean ± SD)

The intervention study revealed no difference in technical performance when comparing the results of the two groups across the batting skills tests ($p < 0.315$; *Appendix E*). Figure 33 indicates little difference between the two groups for the mean targets hit during the pre- and post-intervention tests. The experimental group (7.8 ± 1.6) hit marginally more targets during the pre-intervention test compared with the control group (6.4 ± 1.5). During the post-intervention test, the experimental group (6.0 ± 1.6) decreased the average number of targets hit below that of the control group (6.2 ± 1.1). The control group maintained a similar performance across both tests. The results indicate a non-statistical change in performance, specifically for the experimental group. The standard deviation bars show large variations in performance within each group.

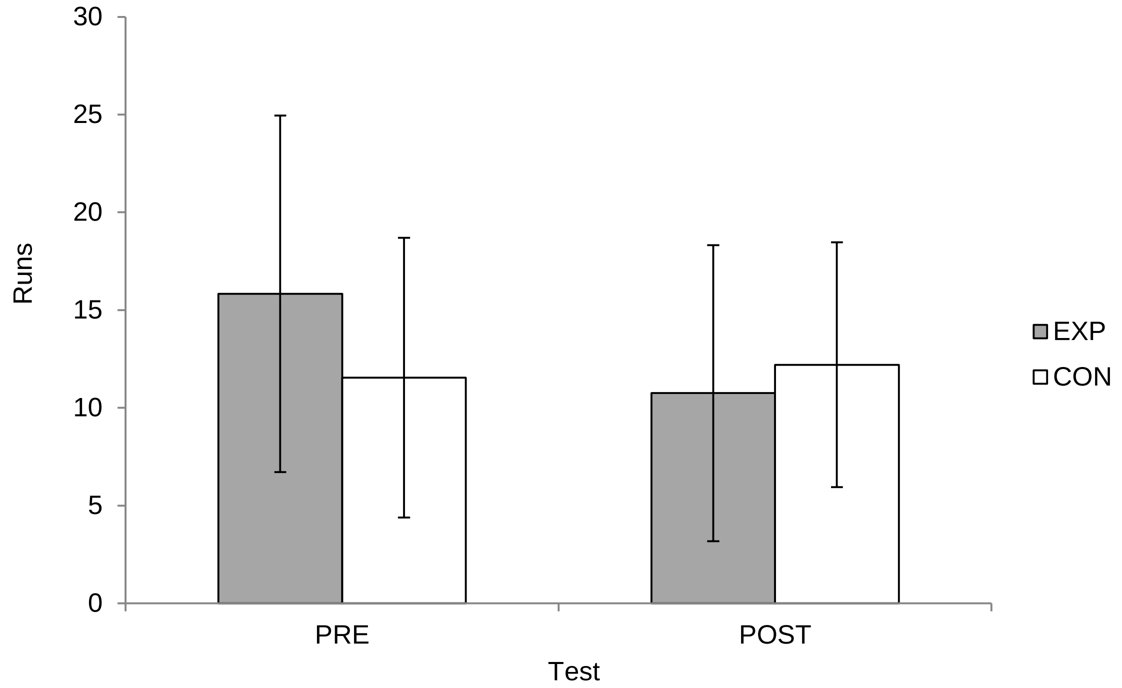

Figure 34: Runs scored for each group, across each test (mean ± SD)

The experimental group averaged noticeably fewer runs during the post-intervention test (pre: 15.83, post: 10.75) (Figure 34). This change in performance was non-statistical.

The differences in the number of targets hit and runs scored during each test resulted in differences (not statistical, $p < 0.338$) in the average number of runs scored per target hit (Table 17). A greater average runs per target hit value indicates a greater degree of accuracy when hitting the targets. During the pre-intervention test, the experimental group averaged 2.03 runs per target in comparison to the control group at 1.80 runs per target. During the post-intervention test, the experimental group averaged 1.79 runs per target (↓ 12%) compared with the control group's average of 1.97 runs per target (↑ 9%).

Table 17: Breakdown of the average runs per target hit for each group across the testing sessions

	PRE	POST	∆%
EXP	2.03	1.79	↓ 12%
CON	1.80	1.97	↑ 9%

Further analysis revealed no differences in performance values during the pre-intervention test. However, the post-intervention test showed significant differences in performance for the variables ‘speed’ ($p < 0.005$) and ‘length’ ($p < 0.04$) (Table 18).

Table 18: The main effects of the 2x2 ANOVA performed on the post-intervention test for the experimental and control groups (speed x length)

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	492.0045	1	492.0045	41.68383	0.000015
GROUP	0.1920	1	0.1920	0.01627	0.900314
Error	165.2455	14	11.8032		
SPEED	72.7375	1	72.7375	10.86793	0.005297
SPEED*GROUP	8.8000	1	8.8000	1.31483	0.270742
Error	93.7000	14	6.6929		
LENGTH	33.6182	1	33.6182	5.12239	0.040039
LENGTH*GROUP	1.5557	1	1.5557	0.23704	0.633887
Error	91.8818	14	6.5630		
SPEED*LENGTH	14.5102	1	14.5102	2.00285	0.178862
SPEED*LENGTH*GROUP	15.8227	1	15.8227	2.18401	0.161593
Error	101.4273	14	7.2448		

As no differences were seen between the two groups ($p < 0.9$), the differences noted in Table 18 were as a result of the combined performance of the sample. The significant differences in the variables ‘speed’ and ‘length’ are shown in the differences in performance across each condition during the post-intervention test (Figure 35).

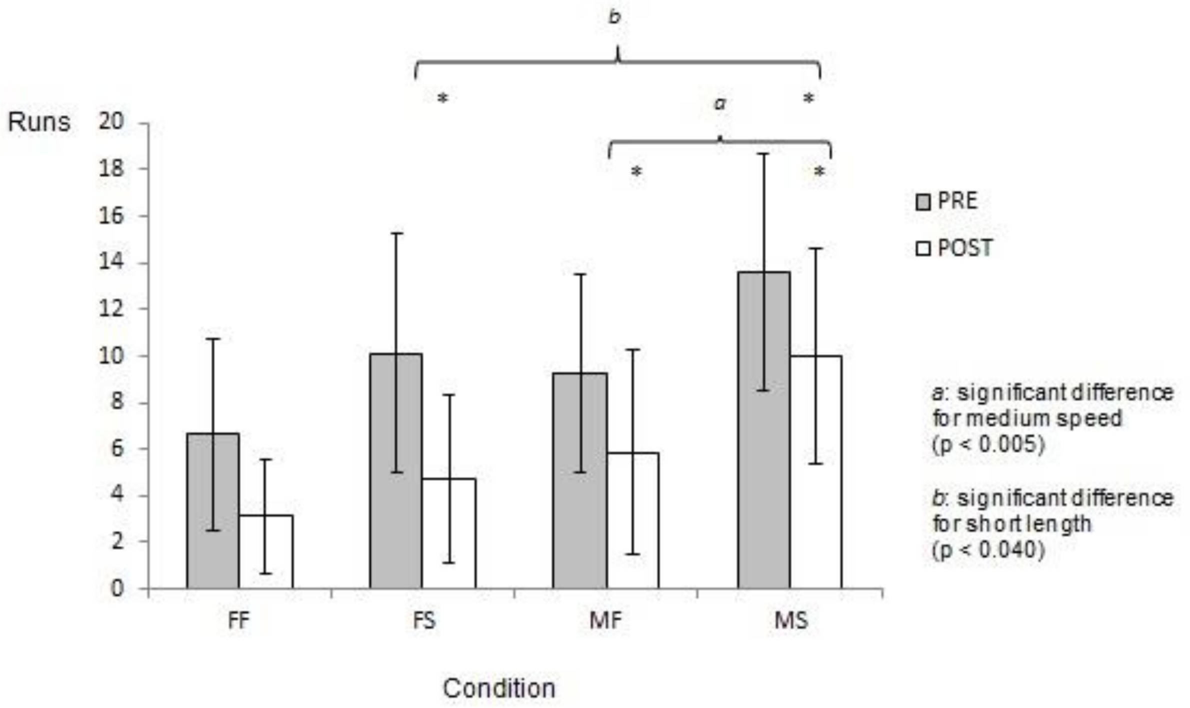

Figure 35: Breakdown of runs scored during each condition, as a combined group (mean ± SD)

Significantly more runs were scored during the medium speed conditions when compared with the fast speed conditions during the post-intervention test ($p < 0.005$; Figure 35). The short length conditions within each speed produced significantly more runs when compared with the full length conditions within each speed during the post-intervention test ($p < 0.04$; Figure 35). No significant differences were noted for the pre-intervention test performances.

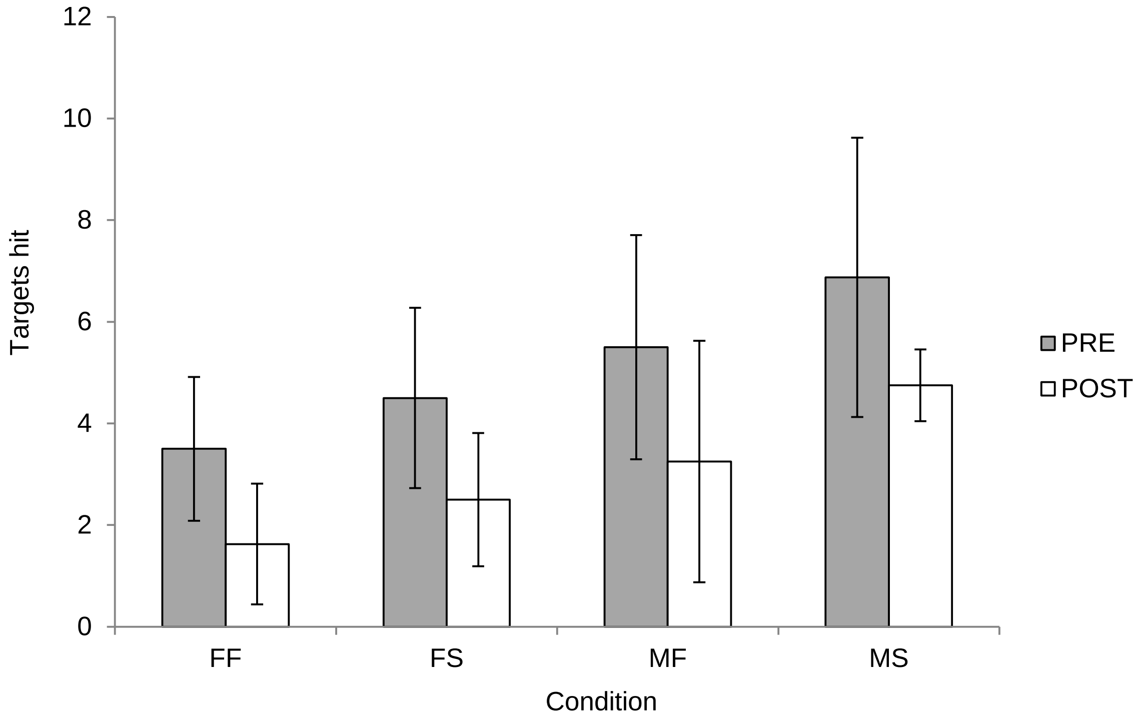

Figure 36: Breakdown of targets hit during each condition as a combined group (mean ± SD)

Likewise with runs scored, overall, the participants hit more targets under the medium conditions (MF, MS) in comparison with the fast conditions (FF, FS) (Figure 36). Participants also hit more targets in the short conditions (FS, MS) compared with the full conditions (FF, MF) within each speed.

Table 19: Mean runs scored per target hit for each condition during the pre- and post-intervention tests

	FF	FS	MF	MS
PRE	1.89	2.25	1.68	1.98
POST	1.93	1.90	1.81	2.11

The average runs per target hit gives an alternative view of the performance during each condition of the pre- and post-intervention test (Table 19). The condition of fast short (FS) had a decline in the average runs scored per target when observing the pre- (2.25 runs/target) to post-intervention (1.90 runs/target) results. The remaining three conditions had similar or small increases in runs per target hit. The medium short (MS) condition had the greatest degree of accuracy, with an average of 2.11 runs per target hit during the post-intervention test (Table 19).

The chi-squared test was used to assess the distribution of hits to misses within scoring zones across the different conditions. The expected distribution of hits to misses was set at a ratio of three to seven (hits: misses).

Table 20: Pre-intervention test performance as a combined group (p-values)

a = 0.05	FF	FS	MF	MS
0	0.430	0.796	0.877	0.857
1	0.115	0.225	0.568	0.242
4	0.228	0.494	0.514	0.841

The results from the chi-squared tests indicate no significant differences in the distribution of hits and misses during the pre- and post-intervention tests for the combined group (Tables 20 and 21). This indicates that the distribution of hits to misses was similar to what was initially expected.

Table 21: Post-intervention test performance as a combined group (p-values)

a = 0.05	FF	FS	MF	MS
0	0.325	0.678	0.630	1.000
1	0.074	0.183	0.166	0.919
4	0.398	0.307	0.578	0.287

The low p-value of 0.074 recorded for the distribution of the score '1' during the fast full condition indicates that the distribution of targets hit for that zone was different to what was expected during the post-intervention test (however insignificant) (Table 21). Further analysis revealed that the distribution of this score was below what was expected. This evidence supports the results presented in Figure 37 and Table 19, with a low percentage of scoring success for the fast full condition.

Batting skills test: Strengths and weaknesses

The results recorded in this sub-section aimed to provide an indication of the strengths and weaknesses of adolescent cricket batsmen. As there were no differences found between the two groups for each of the tests (Figure 36), the following results were mined from the combined performance data of each group during the pre-intervention testing procedure. The pre-intervention test data was utilized as a 'once-off test' to nullify the effects of the intervention or possible learning effects across tests between both the experimental and control groups.

Table 22: Breakdown of runs scored according to variables during the pre-intervention test; combined and individual group assessment (mean ± SD). Number of deliveries within each variable is shown in brackets

Variable	ALL	EXP	CON	*p*
Total Medium Speed (18)	7.96 ± 5.78	8.58 ± 6.86	7.27 ± 4.56	0.76
Total Fast Speed (18)	5.83 ± 4.33	7.25 ± 4.41	4.27 ± 3.85	0.54
Total Full Length (18)	5.52 ± 5.21	6.17 ± 6.18	4.82 ± 4.09	0.62
Total Short Length (18)	8.26 ± 6.15	9.67 ± 6.44	6.73 ± 5.71	0.74
Total Fast Full (9)	2.30 ± 3.28	3.25 ± 4.11	1.27 ± 1.68	0.67
Total Fast Short (9)	3.52 ± 3.09	4.00 ± 2.63	3.00 ± 3.58	0.40
Total Medium Full (9)	3.22 ± 3.37	2.92 ± 3.18	3.55 ± 3.70	0.64
Total Medium Short (9)	4.74 ± 4.09	5.67 ± 4.87	3.73 ± 2.94	0.70
*Total Legside (16 - 20)***	6.35 ± 4.15	7.25 ± 4.25	5.36 ± 4.01	0.75
*Total Offside (16 - 20)***	6.78 ± 5.49	7.75 ± 6.06	5.73 ± 4.86	0.46
*Total Mid-on (4 - 5)***	2.04 ± 2.25	2.25 ± 2.42	1.82 ± 2.14	0.82
*Total Mid-off (4 - 5)***	1.39 ± 1.85	1.75 ± 2.05	1.00 ± 1.61	0.83
*Total Mid-wicket (4 - 5)***	1.65 ± 1.61	1.75 ± 1.71	1.55 ±1.57	0.31
*Total Extra-cover (4 - 5)***	2.39 ± 2.74	2.83 ± 3.41	1.91 ± 1.81	0.41
*Total Square-leg (4 - 5)***	1.57 ± 1.99	2.17 ± 2.04	0.91 ± 1.81	0.58
*Total Cover-point (4 - 5)***	1.61 ± 1.92	1.67 ± 1.87	1.55 ± 2.07	0.12
*Total Fine-leg (4 - 5)***	1.09 ± 1.59	1.08 ± 1.78	1.09 ± 1.45	0.55
*Total Third-man (4 - 5)***	1.39 ± 1.85	1.50 ± 2.02	1.27 ± 1.74	0.20
Total 4's hit (36)*	0.80 ± 0.82	1 ± 0.92	0.59 ± 0.67	*
Total Score (36)	13.78 ± 8.35	15.83 ± 9.12	11.55 ± 7.16	0.93

******Total 4's hit is the only variable that is not recorded as runs scored.*

***Due to the self-selected design for the ninth delivery within each condition, the number in the brackets represents the range of minimum to maximum number of deliveries faced.*

Table 22 summarizes the breakdown of performance of the experimental and control group. The standard deviations indicate a large variation in performances of participants within each group. The p-values show a lack of significant difference between the two groups.

The adolescent batsmen scored more runs during the medium conditions (7.96 ± 5.78) compared with the fast conditions (5.83 ± 4.33). The same can be seen for the difference between the full and short length conditions, with the short length (8.26 ± 6.15) outscoring the full length condition (5.52 ± 5.21). There was very little difference observed between scoring averages of the off-side target zones (6.78 ± 5.49) and the leg-side target zones (6.35 ± 4.15).

It can be seen that the most successful condition was that of the medium short condition, which recorded the greatest average runs scored (4.74 ± 4.09). The fast full condition recorded the lowest average of runs (2.30 ± 3.28).

Looking at the individual target zones, the extra-cover target had the highest average for runs scored (2.39 ± 2.74), resulting in the most successful overall and off-side target zone. The fine-leg target zone recorded the lowest average for runs scored (1.09 ± 1.59), resulting in the worst overall and leg-side scoring zone. The mid-on target zone (2.04 ± 2.25) had the highest scoring average among the leg-side target zones, whereas the third-man target zone (1.39 ± 1.85) had the worst scoring average for the off-side target zones.

The average number of 4's hit during the protocol was less than one (0.80 ± 0.82). The sample averaged 13.78 (± 8.35) runs during the 36-ball batting skills test. Figure 37 provides a graphical representation of the results for each condition.

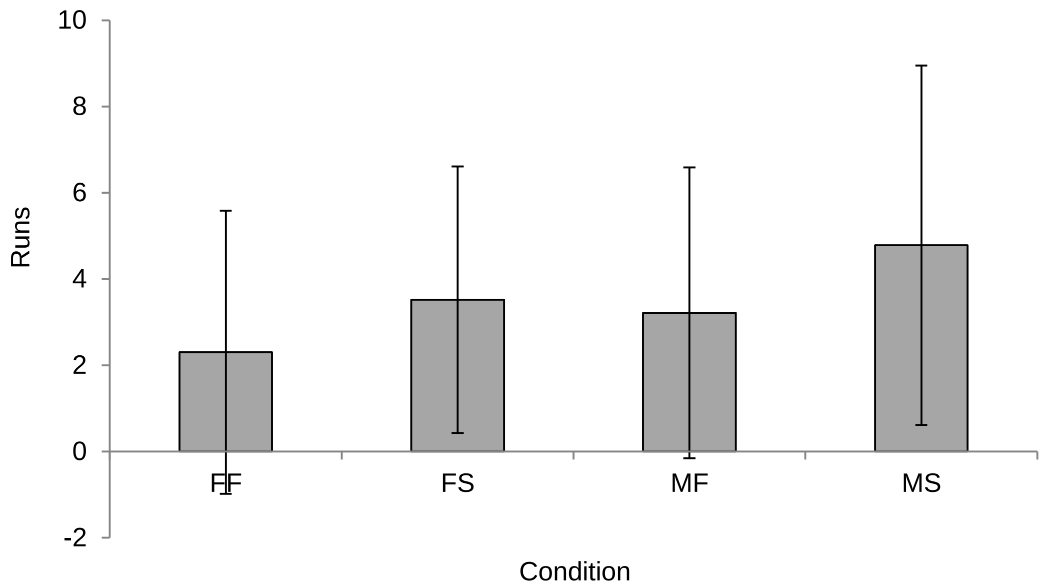

Figure 37: Breakdown of runs scored during each condition during the pre-intervention test, as a combined group (mean ± SD)

Although no significant differences are shown between the four conditions ($p < 0.156$), the medium short condition recorded the highest number of runs.

In summary, adolescent cricket batsmen scored more runs when facing the slower speed conditions compared with the fast speed; the same can be said for the shorter length conditions within each speed. There were no differences in the scoring average between off-side and leg-side target zones. The target zone with the highest scoring average was the extra-cover zone. The worst scoring average target zone was fine-leg. The average runs scored during the 36-ball batting protocol was 13.78 (± 8.35).

Self-selected performance

The final delivery within each condition was required to be hit through a self-selected target zone. This sub-section served to investigate the subjective nature of scoring zones, as well as determine the success at which this objective was performed. As with the section before, only the pre-intervention data was utilized for this sub-section. The results are presented as a combined group, with the purpose of exploring the self-selected scoring zones for adolescent cricket batsmen. These zones were mid-on (MDON), mid-off (MDOF), mid-wicket (MDWK), extra-cover (EXCV), square-leg (SQLG), cover-point (CVPT), fine-leg (FNLG), and third-man (THMN).

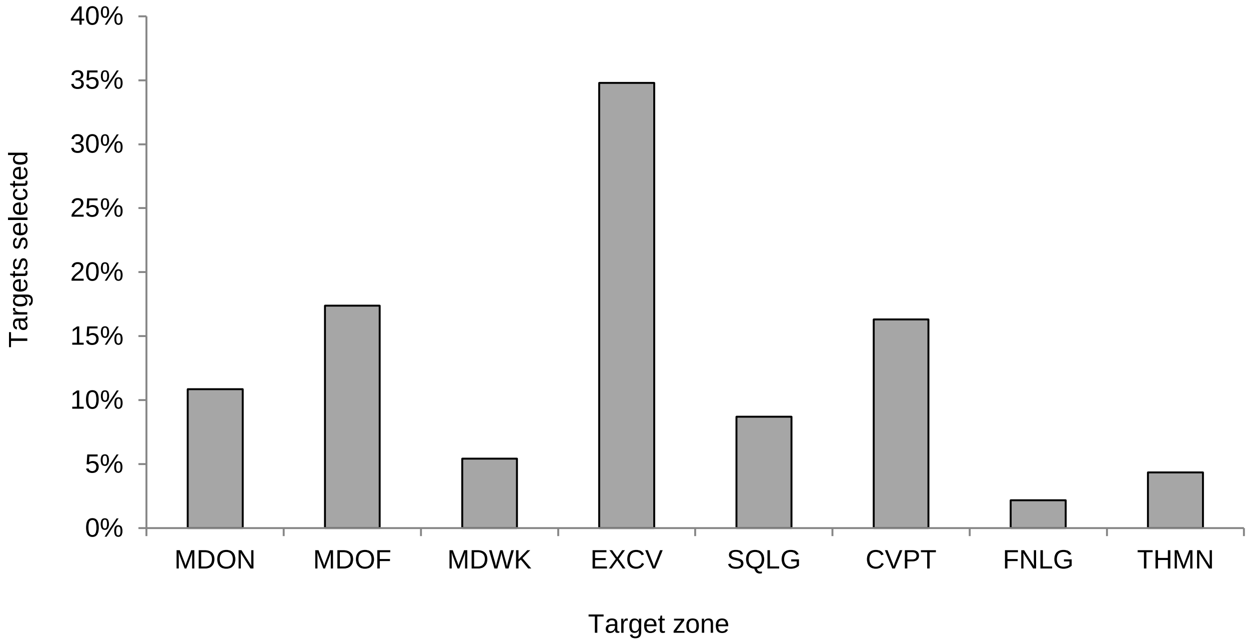

Figure 38: Combined group percentage breakdown of self-selected targets during the pre-intervention test

Figure 38 illustrates the percentage breakdown of the self-selected targets during the batting skills protocol. The most popular target zone selected by adolescent batsmen was the extra-cover zone (35%). The least popular target zones selected were fine-leg (2%), third-man (4%), and mid-wicket (5%). The remaining four target zones were spread from 9% to 17% (Figure 38).

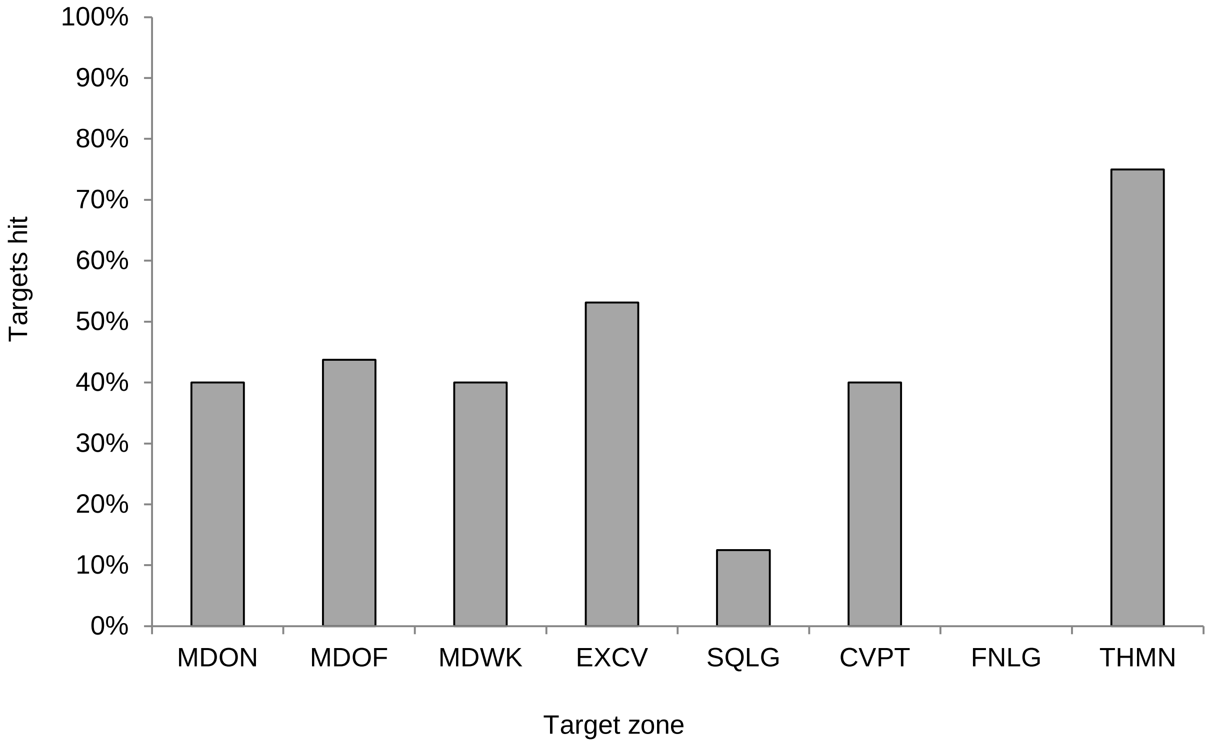

Figure 39: Combined group percentage breakdown of self-selected targets hit during the pre-intervention test

Figure 39 illustrates the success of self-selected targets hit. This figure should be interpreted with Figure 38, as the percentage of targets selected may influence the percentage of success of targets hit. For instance, the third-man target zone had a high level of accuracy (75%), although only 4% of deliveries were selected to hit the third-man target (Figures 38 and 39). The extra-cover target yielded a success rate of 53%, which resulted in substantially higher runs scored compared with the remaining targets as this was selected for 35% of the deliveries.

The majority of targets had a success rate of ± 40%, this included the targets: mid-on, mid-off, mid-wicket, and cover-point. The least successful scoring zones for the self-selected deliveries were the fine-leg target and the square-leg target. Participants failed to hit the fine-leg target zone during the batting protocol, indicating a high level of difficulty for this area. The square-leg target zone had a success rate of 13%, indicating a difficultly to successfully find this target zone.

To summarize, adolescent cricket batsmen favoured hitting deliveries through the extra-cover area (Figure 38). The majority of runs were scored through this target area, with an accuracy level higher than any other scoring zone (Figure 39). The least favoured areas to hit deliveries through were fine-leg, third-man and mid-wicket (Figure 38). The least successful scoring zones were the fine-leg and square-leg targets (Figure 39).

LIMITATIONS OF STUDY II

There were a number of complications which transpired throughout the duration of this research study. These complications were mostly unanticipated, resulting in alterations to the intervention design and consequently the interpretation of the data. The two major alterations to the original study design were made to the number of intervention sessions that were staged during the cricket season and to the sample size of the control group for the post-intervention test. The major limitations of this study have been discussed in the following sections.

Intervention length (Training sessions)

The original schedule for the training intervention proposed one intervention session and one normal training session per week for the eight-week season. With the understanding that the cricket season was eight weeks in length, the first and last weeks were scheduled for the pre- and post-intervention tests respectively, thus leaving six weeks for intervention training. It was only discovered after the commencement of the intervention protocol that the length of the season was reduced by two weeks, cutting the original eight-week season into a six-week season.

Consequently, the original design of six training intervention sessions, spread across six weeks of the cricket season, had to be restructured to four intervention sessions. This was due to the breakdown of cricket seasons at an adolescent level in South Africa. As summer runs from October to March, the cricket season is separated by the school summer holidays. Therefore, each adolescent cricket season is six weeks in duration, either side of the school summer holidays.

As participants were required to perform the pre- and post-intervention tests in the first and last week of the cricket season respectively, only four weeks of intervention training were possible. Unfortunately, one week of training was lost due to poor weather conditions, with an unusually wet summer season. As a result, the experimental and control groups lost one week of training each, with the experimental group only afforded three training intervention sessions during the entire cricket season.

Implementing a training intervention design comprised of only constraints-led training sessions was not plausible as there would have been no compliance from participating schools to partake in the study. The participating schools were generous in the regard to allow the researcher to conduct the study within their school training environment. Removing the role of the coach would not have been feasible, therefore introducing twice weekly sessions of constraints-led training for the four-week period was not an option.

It would be naïve to believe that three intervention training sessions would suffice for an appropriate analysis of a motor learning theory. Although literature is not clear on a minimum requirement of opportunity for participants to adapt a motor skill, it is expected that a task as complex as cricket batting would need a much greater affordance to training sessions in order to see a substantial effect.

Sample size

At the start of the collection period, the size of the sample that participated in the pre-intervention measure was twenty-three (23) participants. Two weeks prior to the scheduled post-intervention measure, one of the control group schools dropped out of the study completely. This reduced the control group sample size from eleven participants during the pre-intervention test to six participants during the post-intervention test. Furthermore, one participant from each group dropped out of the study preceding the post-intervention test (EXP: n = 11; CON: n = 5). As a result, the size of the sample group decreased from twenty-three (23) participants for the pre-intervention test, to sixteen (16) participants during the post-intervention test.

As the dropout rate was so high, it was difficult to make any conclusive comments on the results that were recorded. As such, the results described previously for the control group performances should not be misinterpreted.

Intervention protocol

The main objective of the research study was to train batsmen to manipulate the ball around the playing surface. This would result in less deliveries being hit to fielders, resulting in less dot balls being faced, which would then amount to bigger totals being scored. However, when implementing the intervention protocol, it would have been counterintuitive to force batsmen to run only when they hit the delivery through a designated target area. The principles of the constraints-led approach to training required the practice session to be as representative as possible to the real performance environment. As such, if a run was afforded to a batsman who did not hit the delivery through the target area, they were encouraged to run as they would in a normal competitive setting.

Due to the flow of the training sessions, some batsmen faced deliveries from medium-fast bowlers only, whereas other batsmen faced deliveries from a variety of bowlers, including fast-medium and slow-spin bowlers. This introduced discrepancies between affordance for each batting pair during the intervention session. With that said, this was the standard procedure for all training sessions. Coaches often attempt to replicate real match situations in these training sessions, with different batting roles receiving different batting requirements. For example, opening batsmen would be required to face a batting scenario where they are instructed to 'build an innings' and 'see off the new ball'. On the other hand, middle order batsmen would be given a different set of instructions which would be more representative of the batting scenarios later on in an innings.

In an ideal scenario, the constraints-led intervention protocol would have allowed both the experimental and control groups to train on a centre-wicket, under the same conditions. Therefore, each group would be required to undergo the same deliveries, the same length and the same speeds of delivery. The only difference between the two groups would be the requirement of the experimental group to train by hitting specific targets around the field. The control group would be allowed to hit deliveries in any direction, as they would in normal training situations.

Alterations to intervention training session design

Training intervention sessions were required to be altered due to batting patterns not conducive to learning. The researcher noted that batsmen were reluctant to rotate strike for fear of receiving fewer deliveries than their batting partner. In an attempt to counteract this, the following training session aimed to incentivise batsmen to face more deliveries, by rewarding each batsman with a further two deliveries to face for every target cone that was hit.

The self-selected aspect of the altered protocol introduced the element of chance, whereby participants could potentially hit a target zone that was not the intended zone to be hit. Although some instances of this could be accounted for and thus recorded as missed targets, not all instances were of this nature. Therefore, a few cases of successful targets hit may be misinterpreted.

Performance variability

A major limitation of measuring skill capability within an interceptive-manipulative sport such as cricket batting is that of performance variability. There are a number of factors that influence the consistency of skilled performance (Tucker & Collins, 2012). As there are many degrees of freedom involved in the movement patterns of cricket batting, resulting in a number of anomalies which may influence a good or poor performance.

When measuring for a learning effect in experienced participants, there is a need to evaluate a number of performances of an individual to gauge a norm. This would provide a far more accurate idea of a participant’s capability, rather than a once-off measure. A once-off measure, particularly for highly skilled tasks, does not take into consideration possible discrepancies in performance due to sub-standard or above-average instances. Unfortunately due to time constraints of the cricket season and each participant’s personal time, an average performance measure could not be ascertained. Participants were only measured once during the pre- and post-intervention tests, introducing the possibility of fluctuations in performance, as well as effects of environmental conditions and arousal levels at the time of data collection. As such, participants’ scores for the pre- and/or post-intervention tests may or may not have been a true reflection of their skill capability. If discrepancies did occur within either test, the resulting ‘changes’ in performance may be misinterpreted completely. The use of a retention test was also discarded due to the limited time constraint at the end of the cricket season. An ideal experimental design would have included this measure to accurately infer whether learning effects took place.

Participant absenteeism

One of the difficulties of intervention research is maintaining the sample’s adherence throughout the intervention period. This is particularly difficult on an adolescent population as it is common for individuals to be involved in a number of extra mural activities, limiting their availability to maintain the requirements of the intervention period.

There were two instances were a participant was absent from a training intervention due to involvement in a competitive match of another sporting code. Consequently, these participants ‘lost out’ on one training session each.

Environmental influences

Due to the nature of the sport and the equipment which is used, cricket is abandoned when it rains. The rain affects the leather balls, the wood of the cricket bats and wickets, as well as the turf pitches that are used. Therefore, rain has a major influence on the scheduling of intervention sessions. One intervention session was cancelled due to rain, with another session cancelled as a result of a pitch not prepared due to the inclement weather.

As this was study preformed within a school environment, controlled practice schedules were adopted from each school. So if inclement weather was forecasted for a specific period, these training sessions would invariably be cancelled and the participants would ‘miss’ a training block. However, as the four participating schools were in the same geographical area, inclement weather usually affected all four schools equally and therefore all participants were without practice. This controlled the amount of practice that was performed throughout the cricket season by each school.

The quality of the turf pitches that were prepared for each intervention session was excellent, with zero noticeable differences between the performance of the pitch between schools and across training and testing sessions. As the ball projection machine used hard plastic balls, little damage was incurred by each pitch after a training session. Therefore, each participant was afforded equal quality of pitch to train and test on.

CHAPTER V

DISCUSSION

This chapter discusses the results of each study independently. Firstly, it will discuss the results of the profiling database in the context of South African adolescence and cricket research; and secondly, it will discuss the intervention efficacy and capabilities of adolescent cricket batsmen to manipulate the ball around the playing field, including strengths and weaknesses of adolescent stroke-play and the preferred scoring zones of adolescent batsmen.

The efficacy of the intervention implemented in *Study II* cannot be determined conclusively as a consequence of the study's limitations, summarized in the previous chapter.

STUDY I: PROFILING DATABASE

The aim of this study was to establish a profiling database for adolescent cricket players in the Eastern Cape province of South Africa. A total of 90 (u13: n = 40; u15: n = 50) participants voluntarily participated in measurements pertaining to: anthropometry, morphology, flexibility, and physical performance parameters. Anthropometric and morphological differences have been established between batsmen, bowlers and all-rounders at an international, provincial, county and state level (Stretch *et al*., 2000), however no investigations, according to the author's knowledge, have been made in an adolescent cricket population.

As literature is short on information about South African adolescent anthropometric, morphological, flexibility and physical performance data, the results of this study have been contextualised with datasets from across the world for various measures within each age group.

Anthropometry

There were significant, and expected, differences in anthropometric profiles between the two age groups. The u15 age group were significantly taller (1725 ± 74 mm; $p < 0.0001$) and weighed more (61.6 ± 8.9 kg; $p < 0.0001$) compared with the u13 age group (stature: 1561 ± 95 mm; mass: 51.2 ± 14.8 kg) (Table 10). Placing the u13 cohort's anthropometric data into context, South African normative values at this age are 1541 ± 99 mm for stature and 44.6 ± 11.5 kg for mass (Armstrong, 2009). The average mass of the u13 cohort was greater than the norm, which could explain the differences in body fat percentage between the two age groups in this study. The stature was similar to normative values for the u13 population.

Data from age-matched Australian junior cricket players (Pyne *et al*., 2006) were similar to the results of the u15 cohort in this study. The Australian cohort had similar age (both 14.8 years), stature (1757 mm compared to 1725 mm for the Australian and South African cohorts respectively), and mass (65.8 kg for the Australian cohort compared to 61.6 kg for the South African cohort) measures compared to the South African u15 cohort.

It is believed that the differences between age groups can be attributed to further physiological development, associated with the onset of pubescence (de Onis & Habicht, 1996; Daniels, Arnett, Eckel, Gidding, Hayman, Kumanyika, Robinson, Scott, St. Jeor, & Williams, 2005). The increased hormonal activity assists with the growth of male adolescents, but is not directly related to chronological age (de Onis & Habicht, 1996; Daniels *et al*., 2005). That is to say, the onset of puberty occurs at different periods for different adolescent individuals and not at a pre-determined, fixed stage.

There were no differences in either age group according to playing positions for stature or mass (Figures 17 and 18). This is in contrast to elite players where it has been shown that differences occur (Stretch *et al.*, 2000). Bowlers (and specifically fast bowlers) are taller and heavier (more lean muscle mass) than batsmen (Stretch *et al.* 2000). Therefore, the results of this study either suggest a change has occurred or, more likely, that these differences occur later in the developmental years. Differences in anthropometry, more specifically somatotypes, are noted for playing positions in other sporting codes such as rugby (Smart, 2011) and football (Hazir, 2010), but no specific mention is made to the differences in limb lengths for the various playing positions.

It is believed that a combination of stature, mass and arm length (acromion to radial styloid process) may play a role in ball velocity of American and Korean baseball pitchers (50% of variance explained by these variables), with body mass believed to be the greatest influence (Escamilla, Fleisig, Barrentine, Andrews, & Moorman III, 2002). Further research, with a broader range of age groups (i.e. 13 – 18 years), is required to identify if (or when) discrepancies in anthropometry occur between playing positions.

There was no effect of month of birth (relative age effects) on measures of stature and mass across either age group (Figures 19 and 20). Previous studies analysing month of birth effects on sporting performance have suggested that a high percentage of elite sports athletes are born during the first quarter of the calendar year (Glamser & Vincent, 2004; Baker & Logan, 2007; Williams, 2010). However, results from this study indicated that those 'talent' differentials were not directly related to stature or mass during the u13 and u15 adolescent years. This could be interpreted in a number of ways: firstly, it may be interpreted that there were no potential elite sportsmen within the two cohorts (n = 90), therefore explaining the lack of variance for month of birth effects. Relative age effects for elite sports personnel are difficult to interpret, as longitudinal data would be required from a young age for a great sample of participants, up until an appropriate, elite age. Currently, studies on relative age effects are retrospective in design, as researchers select current elite athletes to assess for month of birth influences. Secondly, it may be interpreted that anthropometric variables are not associated with talent development in skill-based sports, but are more associated with low-skill, physical sports (such as rugby and football). Or thirdly, it may be interpreted that early talent indicators are not necessarily correlated with stature or mass. Current research on relative age effects has been unable to identify specific physiological, anthropometrical, technical, or psychological differences that are present at early ages which are responsible for early identification and specialization of sports personnel. It is believed that maturation is responsible for initial discrepancies among same-aged individuals, but withers out as individuals' progress through pubescence (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). The u15 age group had less variance compared with the u13 age group, possibly as a result of all participants undergoing puberty changes.

In terms of limb length, the u15 age group recorded significantly greater values for each of the four limb segments: upper arm (± 22.9 mm; $p < 0.0001$), lower arm (± 28.9 mm; $p < 0.0001$), upper leg (± 36.9 mm; $p < 0.0001$), and lower leg (± 36.1 mm; $p < 0.0001$) (Table 11). No differences were recorded between playing positions for each of the four limb length measures, across each of the age groups (Figures 21 and 22). Limb length differences do occur among cricket players according to specialized playing positions (Dana *et al*., 2014). More specifically, Dana *et al.* (2014) found that South African fast bowlers had significantly longer arms compared with spin bowlers. However, no differences were noted between fast bowlers and batsmen (Dana *et al.*, 2014). However, the results of this study suggest that anthropometric differences in playing positions are not apparent during the u13 and u15 adolescent years. It may be the case whereby physical prowess plays a more dominant role in the selection of adolescent cricket players to specific positions, rather than technical skill differences which become more apparent for older, more elite cricketing cohorts.

Data examining the limb lengths of Australian fast bowlers (Stuelcken *et al*., 2007) showed similar dimensions compared with the results of u15 cohort. The upper arm length was longer than the lower arm in both cohorts (354 mm compared to 268 mm for the Australian cohort, and 312 mm compared to 263 mm for the South African u15 cohort). The Australian cohort had a longer lower leg length (497 mm) compared to the upper leg (481 mm), whereas the South African u15 cohort had a longer upper leg length (422 mm) compared to lower leg (415 mm). Discrepancies may have occurred in the manner in which the limb lengths were determined and measured. The limb length measurements used in this study were non-invasive, yet not selected as the preferred method for limb length measurement. Stuelcken *et al.* (2007) failed to report the method in which limb lengths were obtained. Note must be taken that the Australian cohort was older (23.5 years compared to 14.8 years), taller (1880 mm compared to 1725 mm) and weighed more (87.9 kg compared to 61.6 kg) compared to the South African u15 cohort.

Morphology

Body mass index (BMI) was similar between the two age groups (u13: 20.65 ± 0.04; u15: 20.68 ± 0.03), but body fat percentage was significantly ($p < 0.0049$) higher in the u13 age group (Table 12). The higher relative body fat percentage for the u13 age group (± 2.84 %) may be due to excess adipose tissue, common in pre-adolescence (Daniels *et al*., 2005). The BMI and body density values were similar across the two age groups (Table 12), suggesting that the u15 age group may have lost some of this excess adipose tissue with the onset of puberty (Daniels *et al*., 2005).

According to the National Centre for Chronic Disease Prevention and Health Promotion (NCCDPHP, 2000), the 5th to 95th percentile range of BMI values for South African u13 males is 15.4 $kg.m^{-2}$ to 25.4 $kg.m^{-2}$, with the average measure of 18.4 $kg.m^{-2}$ (50th percentile). The u13 age group's BMI of 20.65 $kg.m^{-2}$ falls closer to the 75th percentile of this range. As such, the u13 age group is ranked in the acceptable, healthy BMI range (NCCDPHP, 2000). The 5th to 95th percentile range of BMI values for South African u15 males is 16.6 $kg.m^{-2}$ to 26.8 $kg.m^{-2}$, with the average measure of 19.8 $kg.m^{-2}$ (50th percentile) (NCCDPHP, 2000). The u15 age group's BMI of 20.68 $kg.m^{-2}$ falls closer to the 60th percentile of this range. As with the junior age group, the u15 age group is ranked in the acceptable, healthy BMI range (NCCDPHP, 2000). The difference in percentile ranking between the u13 (± 75th percentile) and u15 (± 60th percentile) age groups supports the theory that the younger age group in this study may have had excess pre-adolescence adipose tissue in comparison with the u15 age group.

Data from a study analysing body composition differences among playing positions in a university cohort (Dana *et al.*, 2014) revealed similar results to this study, with no differences recorded for body fat across each of the playing positions, within each age group (Figure 23).

Flexibility

Flexibility measures indicated that the u13 age group recorded significantly ($p < 0.03$) greater measures for trunk extension, with no differences in shoulder extension and hamstring flexibility between the cohorts (Table 13). Differences in trunk extension measures could be related to stature and mass, with the u13 age group being shorter and lighter than the u15 age group (see *Correlations* section to follow).

Placing the hamstring flexibility measures into context, normative values for South African u13 males are 202 ± 75 mm for the sit-and-reach board (Armstrong, 2009). This was performed on a sit-and-reach board with 500 mm of overhang, with the toe line on the 150 mm mark (Armstrong, 2009). The sit-and-reach board used in this study had 400 mm of overhang, with the toe line on the 0 mm mark. Therefore the 68 mm mean recorded for the u13 cohort would equate to 118 mm on the sit-and-reach board used by Armstrong (2009). This was well below the normative values for this cohort. The large variance provides evidence of inter-individual differences within each age group (Figure 24). No differences were found when analysing the flexibility measures across the four playing positions within each age group (Figure 24).

Physical performance

The u15 age group recorded significantly ($p < 0.0001$) greater scores for the physical strength measures compared with the u13 age group (Table 14). This result was expected as the u15 age group were more developed than their u13 counterparts. Putting the u13 cohort's standing jump performance into a South African context, the 165 cm result of the u13 group was below the average distance of 184 cm for this age group (Armstrong, 2009). This may be related to higher average mass and BMI measures compared to the normative values. The 'relatively' heavy u13 participants may not have been able to create as much explosive power required for the standing jump test as participants with lower mass/BMI/body fat measures (Figure 32).

Comparing the result of the u15 cohort's arm strength (overhead medicine ball throw) with a similar aged Portuguese handball cohort (Vieira, Veiga, Carita, & Petroski, 2013), the u15 cohort indicated a similar, yet slightly greater level of arm strength, with an average of 6.3 m, whereas the comparative age group recorded an average of 5.7 m.

The u15 age group recorded a significantly ($p < 0.0001$) faster sprint time for the Illinois agility test compared to the u13 age group (Table 15). A moderate effect size of 0.92 (u15) was found for the practical significance of this variable. A study by Stretch and Buys (1991) noted no differences in speed and agility between the four primary playing positions in a South African university cohort, as was the case in this study for each age group (Figure 26). It may be that the high-intensity, intermittent nature of cricket gameplay requires some level of fitness across all playing positions; whereas other sporting codes, such as rugby union, have noticeable differences in speed performance across playing positions (forwards vs. backline players), where speed is traded-off for greater muscular strength attributes (Smart, 2011).

Correlations

There were no significant correlations for either playing position or month of birth effects across any of the variables measured. This was in line with results from the independent t-tests, which failed to establish significance for playing positions or month of birth effects.

The common trend from the correlation figures indicated that the u13 age group had a stronger correlation with the variables of interest (Figures 27 to 32). This suggests a greater linear effect between anthropometric and morphological variables and physical performance variables for the u13 age group. The u15 age group showed significantly greater measures for each of the physical performance variables, although with less correlation than the u13 cohort. It may be that the discrepancy in the onset of puberty for the u13 age group is responsible for higher correlation values. Those u13 individuals who have entered the 'puberty period' may have distinct differences in physical performance measures compared with their pre-puberty counterparts, due to the presence of additional hormonal activity. Conversely, the u15 age group may have less variance (and correlation) as the effects of puberty are less influential, thereby 'levelling the playing field'.

There was a strong correlation ($r = 0.72$) between stature and overhead throw, with taller participants able to throw the medicine ball further (Figure 27). This was more so for the u13 age group, with the u15 age group showing a much weaker correlation ($r^2 = 0.05$). Assessing the segments of the arm, it revealed that the u15 age group had a stronger correlation ($r^2 = 0.11$) between upper arm length and overhead throw (Figure 28), whereas the u13 age group had a stronger correlation ($r^2 = 0.43$) between lower arm length and overhead throw (Figure 29). Studies have suggested that upper torso (pectoralis major and latissimus dorsi muscles) is more closely related to ball release speed rather than body composition as a whole (Portus, Sinclair, Burke, Moore, & Farhart, 2000). Tying in the result of the overhead throw, it is understandable that cricket players with a taller stature and greater upper body strength are associated with fast bowling.

Stature had a small, yet significant, correlation ($r = 0.22$, $p < 0.049$) with trunk extension (Figure 30), with the u13 cohort revealing a marginally greater correlation ($r^2 = 0.05$) compared with the u15 cohort ($r^2 = 0.009$). The results indicated that the u13 age group's shorter participants were able to achieve higher measures for trunk extension. The u15 age group had a greater dispersion, with no obvious relationship between stature and trunk extension (Figure 30). Differences in trunk extension could be related to a number of possibilities present in the u13 cohort, including a lower centre of gravity (CG) due to less weight for head, arms and torso, which may influence the biomechanical lever, and trunk moment, present in the trunk extension test (Briggs, Greig, Wark, Fazzalari, & Bennell, 2004).

This result has also brought to attention the lack of literature on the effect of stature on lower back injuries in fast bowlers. The majority of fast bowling studies have looked at the impact of the ground reaction force and the lumbo-pelvic angle through the delivery stride, inferring associations with lower back injuries (Gray *et al.,* 2000; Stuelcken *et al*., 2007; Johnstone *et al.*, 2013). Although mention is made of stature, there are no correlations between stature and the prevalence of lower back injury occurrences in fast bowlers. It would be interesting to identify if 'relatively' shorter fast bowlers had fewer cases of lower back injuries in comparison with 'relatively' taller fast bowlers. In terms of trunk extension, research has identified an association between poor trunk flexibility and the occurrence of disc abnormalities (Elliot, Hardcastle, Burnett, & Foster, 1992; Woolmer & Noakes, 2008). This evidence, along with the correlation between stature and trunk extension, warrants interest into the investigation of the effects of stature on lower back injuries.

Examining the relationship between agility sprint time and standing jump performance showed a moderate correlation ($r = 0.55$), with a clearer effect for the u13 age group (Figure 31). The u13 cohort recorded slower agility sprint times in participants with shorter standing jump distances ($r^2 = 0.46$). The u15 cohort recorded less variance, with a much weaker correlation between the two variables ($r^2 = 0.03$). These results support literature on leg strength and sprint performance (Comfort, Haigh, & Matthews, 2012), which identify that greater leg strength results in faster sprint performance times.

Body fat percentage had a moderate correlation ($r = 0.54$) with standing jump performance, with participants recording shorter standing jump distances with an increase in body fat (Figure 32). The u13 cohort had a stronger correlation ($r^2 = 0.30$) between the two variables compared with the u15 cohort ($r^2 = 0.14$), indicating more of an effect for the younger age group. The result suggests that participants with a higher relative body fat struggle to jump as far as participants with less body fat. The low correlation (r = 0.06) between mass and standing jump performance suggests that mass alone is not responsible for this discrepancy (*Appendix E*). However, the current results only support literature on leg strength for the u13 age group.

STUDY II: TECHNICAL SKILL IN ADOLESCENT CRICKET BATTING

The batting skills test used to assess the interceptive-manipulative capabilities of adolescent cricket batsmen required participants to manipulate specific deliveries of various speeds and lengths to designated target zones around the playing field. As this intervention study was a first of its kind, a comparative discussion with past literature and findings on similar research cannot be produced. Therefore, the results of this intervention have been discussed in isolation.

Intervention efficacy

Briefly summarized, there were no differences in group performance during the pre- and post-intervention tests when analysing the breakdown of runs scored during the four conditions of the batting skills test ($p < 0.315$; Figure 33). The performance of the experimental and control groups did not differ in comparison with, and against, one another during the pre- and post-intervention tests ($p < 0.228$; Figure 33). A number of factors may be responsible for this occurrence, which will be discussed in further detail.

Looking at the performance of the batting skills tests, it was found that the experimental group recorded non-statistically greater values for runs scored (EXP: 15.83 ± 9.12; CON: 11.55 ± 7.16) and targets hit (EXP: 7.8 ± 1.6; CON: 6.4 ± 1.5) compared to the control group during the pre-intervention test (Figures 33 and 34). However, during the post-intervention test, the experimental group recorded a slight decline in performance, scoring fewer runs and hitting fewer targets than the control group (Figures 33 and 34). Although this occurrence might suggest a difference between the two training groups, the high dropout rate ($n = 7$) overshadows the possible explanation of effect. The small control group ($n = 5$) had far less variance among participants compared with the experimental group ($n = 11$). A meaningful comparison of scores between an experimental group and a control group, with a large discrepancy in group numbers, was considered to be an unreliable interpretation of the findings.

The breakdown of the average number of runs per target hit specifies a level of accuracy to hit the centre of the target zones (Table 17). As the middle cones were rewarded with four runs, having a greater average of runs per target hit indicated a greater number of runs scored within the ‘four runs’ zone. The experimental group (2.03 runs per target) averaged 0.24 runs more than the control group (1.79 runs per target) during the pre-intervention test, resulting in a greater accuracy to find the middle of the target zones (Table 17). However, during the post-intervention test the control group (1.97 runs per target) averaged 0.17 runs more than the experimental group (1.80 runs per target) (Table 17). The experimental group decreased in performance (↓ 12%) from the pre- to the post-intervention test, whereas the control group increased in performance (↑ 9%) from the pre- to the post-intervention test. Not only did the control group improve their performance of targets hit marginally, but they improved their accuracy of targets hit as well. However, the difference noted between the two groups was not statistically different ($p < 0.338$).

A level of significance was established during the post-intervention test, where the combined performance of the two groups revealed a difference in scoring performance between the conditions (Table 18). During this test, participants scored significantly more runs during the medium conditions compared with the fast conditions ($p < 0.005$). It was expected that participants would have a greater success when receiving deliveries from the medium speed conditions compared with the fast speed. This was because batsmen had more time to perceive and act on a delivery, allowing for more emphasis on where the ball should be placed.

Furthermore, participants scored more runs when facing deliveries during the short length conditions of each speed, compared with the full length conditions ($p < 0.04$). It is believed that adolescent cricketers favour cricket strokes where whole body force production can be used to muscle the cricket ball to different areas in the field (Renshaw & Holder, 2009). Full pitched deliveries often require a vertical bat face to hit the ball through the line, while short pitched deliveries often require a horizontal bat (baseball style) to hit the ball to a desired area. Short pitched deliveries offer batsmen the time and freedom to muscle the ball to specific areas in the field; whereas full pitched deliveries may require more technical skill, muscular strength, and timing, to create sufficient force production to hit the ball to desired areas in the field.

In summary, the results of the pre- and post-intervention tests show that there was no difference in performance between the experimental group and the control group in either test (Figure 33). This reveals two facts: firstly, it confirms that the participants were of a similar skill level in terms of interceptive-manipulative capability prior to the commencement of the study; and secondly, it indicates that the intervention implemented for the experimental group failed to assist the development of technical skill during the course of the cricket season.

It was speculated that this lack of evidence may be as a consequence of so few intervention training sessions (n = 3), rather than as a result of the theoretical underpinnings (constraints-led approach) of the intervention protocol (refer to *Limitations* in Chapter IV). As such, a conclusive stance for the approval or rejection of such a training method has not been taken.

Batting skills test performance

This section of the discussion attempts to compare the performance of the adolescent cricket batsmen during the pre-intervention test within the context of the original batting skills test study. The design of the batting skills test was extracted and modified from the original protocol implemented by Portus *et al*. (2010). The authors explored the validity of a batting skills test by evaluating the performances of participants from three differing skill levels: 'Elite' (mean age 31 ± 3 years), 'Emerging' (mean age 22 ± 3 years), and 'Junior' (mean age 18 ± 1 years) level cricketers (*Appendix E*). The conclusions of the study approved the use of the batting skills test to differentiate skill level among cricket batsmen (Portus *et al.,* 2010).

As this study focused on the technical skill of adolescent (u15) cricket batsmen, a comparison of performances with the study of Portus *et al*. should be examined within context. Firstly, the modification of the original batting skills test, with changes in speed of delivery, should have nullified major discrepancies in performance. Secondly, the 'Junior' level cricketers (u19) that participated in the original study were members of the Australian National u18 Talent Camp and the u19 Australian Representatives. Therefore, it can be assumed that these participants were highly skilled batsmen within their respective age groups. Thirdly, it must be noted that an alteration to the width of the scoring zones meant that the adolescent batsmen in this study had a smaller target to hit 'fours' compared with the original cohort of Portus *et al*. (2010). The overall width of the target areas were no different, meaning the adolescent cohort had a larger zone to score 'singles'. These discrepancies in the breakdown of runs scored would have a major impact on the overall scoring of the two cohorts, which would need to be accounted for. As such, when documenting the performance of the adolescent (u15) cricketers, the context of their skill level and the alterations to the test design was a major priority.

The pre-intervention test results were used to evaluate the performance of the adolescent boys in comparison with the 'Junior' level cricketers of the Portus *et al.* study. This was chosen for two reasons: (*i*) the significant portion of participants that dropped out from the pre-intervention test to the post-intervention test; and (*ii*) the pre-intervention test could be considered a 'once-off' test with no possibility of a learning effect taking place, or discrepancies between groups as no intervention sessions would have been implemented.

The adolescent batsmen recorded similar patterns of scoring when compared to the performance of the 'Junior' level cricketers of Portus *et al.* (2010), albeit consistently lower than the scores of the 'Junior' level cricketers (*Appendix E*). There were some noticeable differences in performance, which was understandable due to the expected contrast in skill level between the two cohorts. The major differences between cohorts were noted for the total scores of the variables: 'total medium speed', 'total fast speed', 'total offside', 'total 4's hit', and 'overall total score' (Table 22).

The 'Junior' participants from Portus *et al*. scored on average 14.89 (± 5.85) runs during the 'medium speed' conditions, whereas the adolescent participants in this study averaged 7.96 (± 5.78) runs during the medium conditions. As with the medium speed, the 'Junior' participants (10.6 ± 5.9) scored almost twice as many runs during the 'fast speed' conditions compared with the adolescent participants (5.93 ± 4.33). Similar discrepancies were noted for the total runs scored on the 'offside' ('*Junior'*: 16.51 ± 6.99; *adolescent*: 6.78 ± 5.49), the total number of '4's hit' during the protocol ('*Junior'*: 4.51 ± 2.12; *adolescent*: 0.80 ± 0.82), and the 'overall total' number of runs scored ('*Junior'*: 25.49 ± 9.11; *adolescent*: 13.78 ± 8.35).

A similar pattern of scoring was seen when analysing the performance of the 'total short' and 'total full' variables, with both cohorts scoring more runs during the 'total short' variable. This is emphasised by the differences in performance between the ‘medium full’ condition and the ‘fast short’ condition, with the latter recording a greater average of runs scored. The similar pattern of runs scored indicates that the adolescent batsmen showed similar tendencies with bat in hand compared with the ‘Junior’ level cohort. The major discrepancies between runs scored within each cohort may largely be due to the alteration of the width of the scoring zone. When weighting the scoring zones as drastic as ‘four’ and ‘one’ run respectively, there should be a discrepancy in the dimensions of the scoring zones. Whereas Portus *et al*. awarded the ‘four’ runs zone double the width of the ‘one’ run zone, this study awarded the ‘four’ run zone half the size of the ‘one’ run zone. Hence, the scoring area rewarded the batsmen with more runs for more accurate cricket strokes. And the results of this alteration are evident as the ‘Junior’ participants (4.51 ± 2.12) were able to score a greater amount of runs through the ‘four’ zone compared to the adolescent participants (0.80 ± 0.82).

Chi-squared

The distribution of deliveries between scores ‘zero’, ‘one’ and ‘four’ was not significantly different to what was expected prior to the commencement of the pre-intervention test (Tables 20 and 21). A breakdown of 70% for misses to 30% for hits was assumed for the batting skills test. The reason this was decided upon was due to the spatial constraints of the target zones. The successful hits were further broken down into 20% for hitting target zone ‘one’ and 10% for hitting target zone ‘four’. There was no significant difference in distribution across the four conditions (Tables 20 and 21).

Preferred scoring zones for adolescent batsmen

The final adjustment to the original batting skills test was the self-selected aspect for the final delivery within each condition. This was incorporated to gain insight into the favoured scoring areas of adolescent cricket batsmen. This was a novel aspect of cricket research and as such there was no past literature to compare the results.

The participants selected the ninth delivery of each condition to be hit through the extra-cover zone for ± 35% of the deliveries. This was significantly more than any of the remaining seven scoring zones. The second most common scoring zone was the mid-off (17%) zone, followed closely by the cover-point (16%) zone (Figure 38).

The least common target zones selected to hit deliveries through were that of the third-man (4%) and fine-leg (2%) scoring zones. This was closely followed by the mid-wicket (5%) scoring zone and the square-leg (9%) scoring zone (Figure 39).

It is interesting to note the lack of interest in utilizing the third-man and fine-leg scoring areas for adolescent batsmen. These scoring areas require minimal force production, as both areas are behind the batsmen. As such, batsmen may use the speed of the bowler to deflect the ball to either third-man or fine-leg with minimal effort. Therefore, the faster the bowler delivers the ball, the faster the ball is deflected to each of these scoring areas. With that said, it should also be noted that due to the angle of the bat face and the line of the delivery, it is perceived to be more difficult to manipulate the ball to these areas of the field, compared to hitting in front of the wicket. In real match settings, these strokes might be considered to have a greater risk of dismissal with the introduction of slip fielders and leg-before-wicket (LBW) dismissals. However, as these constraints were absent from the batting skills test, batsmen were aware that the risk of being dismissed was removed from the drill.

The lack of preference, as well as the results during the batting skills test, indicates that the mid-wicket and square-leg scoring zones were a weak area of stroke-play for adolescent batsmen. The inability (and lack of interest) to hit deliveries to these areas of the field should be noted by practitioners, as these two areas cover a large portion of leg-side field space that could provide ample runs for batsmen.

In terms of accuracy to hit the self-selected scoring zones, the participants successfully hit ± 53% of deliveries directed to the extra-cover scoring zone (Figure 39). Participants scored significantly more runs through the extra-cover scoring zone in comparison with the remaining seven zones. The third-man target, although selected for so few deliveries (4%), had a high success rate (75%), indicating batsmen’s capability to deflect deliveries to this area of the field. However, it is interesting to observe the lack of interest to utilize this zone when pressured to score runs (as was the requirement of the ninth delivery).

The target zone with the least amount of success was fine-leg, with no deliveries finding the target zone (Figure 39). Square-leg (13%) was another target zone with very little success (Figure 39). This indicates a weakness of adolescent batsmen to hit deliveries off their legs or hips to desired areas in the field.

Practical application

From a practitioner's perspective, it can be understood that adolescent cricket batsmen prefer hitting deliveries through the off-side scoring areas of extra-cover, mid-off and cover-point. This supports the results discussed previously regarding the strength of batsmen to hit off-side targets compared with leg-side targets (Table 22). Practitioners should encourage adolescent batsmen to train off-side and leg-side stroke-play to be equally strong, thus reducing the amount of deliveries that these batsmen struggle to score runs off.

Adolescent batsmen appear more adept at hitting short length deliveries due to the mechanics of the cricket stroke. The whole body force production allows for hard-hitting strokes to be forced away from fielders more easily. Batsmen with less muscular strength should be encouraged to manipulate the ball around the field by deflecting the speed of the delivery, particularly for full pitched, front-foot strokes where force production results from upper body (arm and shoulder) strength. The third-man and fine-leg scoring areas provide an efficient means to score runs and rotate the strike between batsmen, with minimal force production required. Batsmen with more muscular strength should be encouraged to train manipulating front-foot strokes around the playing field, with as much ease as back-foot strokes.

Practitioners should consider affording these batsmen ample opportunity to train front-foot stroke-play, initially with medium speed conditions and gradually increasing speed as capability increases. The emphasis on manipulating deliveries for front-foot strokes is important, as bowlers start to become more accurate with an increase in age and skill development (Renshaw & Holder, 2009). As a result, short pitched deliveries become fewer in number, and the difficulty of run scoring increases. Those individuals that master the ability to manipulate deliveries to desired areas in the field, with less risk in stroke-play, should find the task of batting easier. The consistent rotation of strike between batsmen relieves the pressure that the bowling team attempt to create, thus reducing the risk of an expansive attacking stroke.

In terms of improving batsmen's capability to manipulate deliveries of a faster speed, practitioners should consider implementing some constraints which afford batsmen more efficient training. For example, shortening the length of the pitch would reduce the amount of decision-making time afforded to batsmen, thus training their reaction times. Once batsmen become used to this new speed, reverting back to a full length pitch should provide them with more time to make decisions based on the type, line and speed of delivery.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

As with the preceding chapters in this thesis, the final conclusions and recommendations have been separated according to study.

STUDY I: CONCLUSIONS

The primary aim of this study was to establish a profiling database for adolescent cricket players in the Eastern Cape province of South Africa. It is clear that there are a number of differences (albeit expected) between the u13 and u15 age groups. The u15 age group were expectedly taller, heavier and had longer limbs compared to the u13 age group (Tables 10 and 11). It was inferred that this was due to physiological differences resulting from pubescence. The u13 and u15 age groups recorded similar measures for stature and mass compared with other datasets of similar ages (Australian and Portuguese cohorts).

Although the two age groups recorded similar values for body mass index (BMI) and body density, the u13 age group recorded significantly higher measures for body fat percentage compared with the u15 cohort (Table 12). It was believed that this may be due to excess adipose tissue associated with pre-adolescence (Daniels *et al*., 2005). The u15 age group was speculated to have lost some of this excess adipose tissue as an effect of the onset of puberty; however this cannot be confirmed as they were not measured at an u13 level. The interpretation of BMI with normative South African adolescent males indicated that both age groups were within the healthy, acceptable BMI range for their respective age groups (NCCDPHP, 2000).

The u13 age group showed greater trunk extension compared with the u15 cohort, with no differences recorded for shoulder extension or hamstring flexibility (Table 13). The u13 cohort recorded lower scores for hamstring flexibility compared with a similar aged South African cohort. The u15 age group recorded significantly higher measures for the physical performance tests compared to the u13 age group (Tables 14 and 15). A comparison between the u15 cohort’s arm strength (overhead throw) indicated similar results with a similar aged Portuguese cohort.

There were expected correlations between variables, including strong correlations between group and: stature, mass, limb length, agility and power variables (*Appendix E*). This was expected due to the significant differences noted in the independent t-tests (*Appendix E*).

The u13 age group recorded stronger correlations compared with the u15 age group across the variables of interest, including stature with overhead throw (Figure 27), upper and lower arm with overhead throw (Figures 28 and 29), stature with trunk extension (Figure 30), agility with standing jump performance (Figure 31), and body fat with standing jump performance (Figure 32). The u13 age group had a greater linear effect between anthropometric and morphological variables and physical performance variables. It is believed that the onset of puberty in some of the u13 individuals may explain the stronger correlations between variables. The taller and heavier u13 participants were able to outperform their shorter and lighter counterparts. The u15 age group had less variance, possibly due to participants all showing effects of puberty.

Trunk extension had a significant correlation with stature, particularly in the u13 age group, with shorter participants able to record greater values for trunk extension (Table 13). It is speculated that the lower mass in the shorter participants, particularly lower head, arms and torso (HAT) mass, would lower the centre of gravity (CG), thus creating less trunk moment at the fulcrum during the trunk extension test (Briggs *et al*., 2004).

Agility sprint time had a significant correlation with the standing jump test, particularly for the u13 age group, with slower participants recording shorter standing jump measures (Table 15). This emphasises the importance of lower leg strength in sprint performance (Comfort *et al.*, 2012). Participants with greater body fat had lower scores for standing jump, possibly due to the excess mass.

There were no differences across any of the variables when comparing with the four primary playing positions (all-rounder, batsman, bowler, and wicket-keeper). The same outcome was found for month of birth effects, with no differences in anthropometric, morphological and physical performance parameters within each age group (Figure 19 and 20, *Appendix E*). This may be due to a number of explanations, such as a lack of ‘talented’ participants in the sample; anthropometric measures may not be associated with early talent indicators in skilled-based sports; or that anthropometric measures, such as stature and mass, are not associated with talent indicators in general.

STUDY I: RECOMMENDATIONS

In order to gain a holistic understanding of the profiling differences in adolescent cricket players, further research should add to the preliminary data presented in this study. Studies should attempt to broaden the knowledge of adolescent cricket profiles, thus ensuring more support to enlighten practitioners such as strength and conditioning coaches.

Although no differences were recorded for playing positions, further research on adolescent cohorts may be able to identify reliability in this finding. It has been established that differences in anthropometric and morphological variables occur between playing positions at a senior, elite level, but there is no indication as to when these differences originate. Further profiling research should incorporate a greater range of age groups, thus including cricketers that are more developed and more established in their roles (playing positions) in the team.

The correlation between stature and trunk extension may provide a point of interest for future research, as injuries to the lower back are most common among tall, fast bowlers (Gray *et al*., 2000). The majority of lower back injury studies focus on the impact forces occurring during the delivery stride and release for fast bowlers, with no indication as to the effect of stature in the injury process. Research interpreting the correlation between stature and lower back injury prevalence may provide added insight as to the causes, and influences, of lower back injuries in predominantly tall, fast bowlers.

STUDY II: CONCLUSIONS

The aim of this study was to determine the efficacy of a constraints-led training intervention to further assist with the development of technical skill in adolescent cricket batsmen. Due to a number of unforeseen limitations, most notably a limited number of intervention sessions (n = 3) and a high dropout rate for the control group (n = 6), the integrity and rigour of the intervention period was jeopardized. As a consequence, participants were not afforded a sufficient number of training sessions to learn the technical aspects of the interceptive-manipulative task. The large discrepancy in group sizes (EXP: n = 11; CON: n = 5) for the post-test measure meant that valid inferences from the results could not be made. With these fundamental design issues in mind, a comparison of the intervention training protocol with that of the traditional net training protocol would be uninformative and unreliable at best. Therefore, the efficacy of this training intervention cannot be answered in its entirety through the results found in this research study.

The performance of the experimental and control groups did not differ between one another or within one another for the pre- and post-test measure. The experimental group recorded marginally less runs during the comparative measure, while the control group recorded marginally more runs during the comparative measure (Figure 33). These differences were non-significant.

Assessing the performance of the adolescent cricketers in the batting skills test during the baseline measure provided evidence of strengths and weaknesses of these batsmen. Participants scored more runs during the medium conditions in comparison to the fast conditions, indicating a preference to bat against a slower speed. Participants also scored more runs for the short length deliveries within each speed condition, indicating a preference to play cricket strokes off the back foot. It is believed that this preference is due to force production and the mechanics of the cricket stroke. The back-foot strokes to short pitched deliveries allow batsmen more time as well as whole body force production to muscle the ball to specific parts of the field. The full length, faster deliveries require more upper body (arm and shoulder) strength, technical skill and timing to hit forcefully to desired scoring areas.

The medium short condition yielded the highest average of runs scored compared with the remaining three conditions (non-significant, Figure 37). There was no difference in average runs scored between the off-side and leg-side target zones combined. The extra-cover target zone had the highest average of runs scored, with the fine-leg target zone recording the lowest average of runs scored (Table 22).

The self-selected parameter in the study design revealed that adolescent batsmen favoured hitting deliveries through the extra-cover scoring zone (Figure 38). This was also the most successful zone in terms of accurate hits in comparison with the other scoring zones (Figure 39). The off-side target zones were favoured for two-thirds of deliveries, with the leg-side target zones receiving one-third of the allocated deliveries. Fine-leg and third-man were the least commonly selected target zones to score runs through. It was surprising to observe how few deliveries were selected to be hit through the third-man and fine-leg target zones, as these areas required the least amount of force production. The nature of strokes to these areas allows batsmen to use the speed of the bowler to deflect the ball behind the batsman, thus requiring minimal effort.

STUDY II: RECOMMENDATIONS

Traditional net settings provide little representation of the real performance environment, with no constraints on the type of strokes hit or the area in which these strokes are hit. As there is such a great variety of cricket strokes, batsmen are not necessarily required to play a broad range of them consistently. Practitioners should not focus on training batsmen to play all variations of cricket strokes, but rather provide each batsman with a repertoire of strokes that would allow them to score runs for any variety of delivery. Thus, it is the responsibility of the practitioner to identify the strengths and weaknesses of each individual batsman’s stroke-play, and train these batsmen to minimize their weaknesses, while reinforcing their strengths.

The lack of attention given to the importance of manipulating deliveries in a training environment may be counterproductive to performance in a real performance setting. The manner in which batsmen currently train is not directly transferred to the real performance environment; improving the representation of training sessions may provide easier transition from training to real match play.

Current adolescent batsmen favour scoring runs off the back-foot through forceful stroke-play. It is recommended that practitioners focus intently on training adolescent batsmen to manipulate the ball around the playing field, specifically for front-foot strokes where more upper body strength and timing is required. Relatively weaker batsmen should be encouraged to use the speed of the bowler to generate force to hit the ball around the playing field. The scoring zones of third-man and fine-leg would provide ample runs for batsmen to attain if more deliveries were deflected through these regions. Practitioners should take individual characteristics into account, such as muscular strength, when training batsmen to play an array of cricket strokes.

The limitations within this intervention study ultimately hindered a successful analysis of the efficacy of a constraints-led approach to training adolescent cricket batsmen. The length of the school cricket season allowed for six weeks of cricket fixtures, with as many weeks for cricket practice. With the first and last week of training scheduled for pre- and post-intervention tests, the cricket season only allowed for four weeks of intervention training. In order to perform a meaningful intervention study during this time scale it would be advised to schedule two intervention sessions per week, to allow for a greater number of sessions afforded to participants.

In hindsight, the study design implemented here would require a larger sample of participants to provide sufficient evidence to support or reject the efficacy of this intervention. The use of school boy adolescent cricketers was the first major limitation of this study design. Although participants within this age category have regular, structured training sessions, the volatility of intervention training and the external factors that influence the training ability of these individuals should be accounted for. It should be cautioned that adolescent participants are encouraged by schools to partake in as many sporting codes as possible, and as such have very limited time to maintain participation throughout an intervention period. A target population with a greater amount of time devoted to cricket training, or with a more flexible schedule may provide for better quality data collection. A cricket academy may provide the perfect population for this question (and others like it) to be tested, as participants would be intrinsically motivated and are afforded ample training time during the course of a season.

It is implored that future research (and analysis) of a constraints-led training approach to technical skill development make use of a rigorous scientific design and critical evaluation of the results thereof. A common theme within intervention training is the difficulty to control extraneous variables which influence the outcome of the intervention study. Most notably, participation dropout reduces the sample size to numbers that may not provide substantial evidence to establish efficacy of the intervention procedure.

To answer the research question as to the efficacy of a constraints-led training intervention to assist the development of technical skill of adolescent cricket batsmen, the hypothesis behind this intervention should be carried out in a more controlled manner, without the scientific discrepancies reported in this study.

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APPENDIX A – STUDY I

Letter of information

Informed consent – Participant

Informed consent – Parent

Informed consent – Coach/Headmaster

STUDY I: PROFILING DATABASE

Letter of information

I am a Master's student in the Department of Human Kinetic and Ergonomics (HKE) of Rhodes University. For my research project I am assessing the anthropometric, morphological and physical performance characteristics of male adolescent cricket players. The purpose of my research study is to establish a database for u15 and u13 male adolescent cricketers. The measurements that I will be performing are as follows:

- Limb length (tape measure)
- Flexibility: Trunk, Shoulder and Hamstring (tape measure & sit-and-reach board)
- Agility (stop watch)
- Power: Overhead medicine ball throw, Rotational medicine ball throw (3kg medicine ball)
- Body composition (skinfold callipers)

The study design is a once-off measuring session, which will be divided into four rotating stations. Participants would be divided into groups of four or five, and rotate between stations. Each station is responsible for a specific measurement, where a trained research assistant would brief the participants of what is required of them. For example, station one would consist of limb length and flexibility measures, where a research assistant would explain to the group, through practical example, exactly how each parameter would be tested. Station two would consist of power measures, where participants would perform an overhead medicine ball throw, a rotational medicine ball throw (left and right), and a standing jump test. Station three would consist of the Illinois agility test, where participants would perform the sprint test. Station four would consist of body composition, where participants would be measured for stature and mass, as well as the seven-site skinfold measure.

The requirements of the testing session are not strenuous, but correct precautions shall be enforced prior to commencement; this includes a static and dynamic warm-up for the participants. The participants would be informed that their involvement within the testing session is completely voluntary and that they may withdraw from the testing session without need for explanation.

All data collected during this session would remain anonymous and confidential, and the results would be published in the Master's thesis and any publications that may ensue. Thank you for taking the time to read through this information sheet and considering participation within this research project.

Kind regards,

Leading Researcher
Matthew Clark
g09c0366@campus.ru.ac.za; 079-335-4126

Project Supervisor
Dr Candice Christie

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STUDY I: PROFILING DATABASE

Informed consent: Participant

I, ________________________, have been fully informed (both verbally and in writing) of the research titled:

ANTHROPOMETRIC, MORPHOLOGICAL AND PHYSICAL PERFORMANCE DATABASE OF SOUTH AFRICAN ADOLESCENT CRICKETERS

I hereby give my consent to act as a participant in the above mentioned study. I have been fully informed, both verbally and in writing, of the testing procedures required for this research study. I am aware that whilst my anonymity will be protected at all times, the results from this research may be used for scientific or statistical purposes. By signing this document, I am agreeing to participate in this research study and have been fully informed of the risks associated with my participation. I have been informed that my participation in the data collection process is voluntary, and that I may withdraw from participation at any time, without need for reason.

I have read the information sheet accompanying this form and understand it. Any questions I may have had have been answered by the researcher to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE):

____________________ ______________________ ___________

(*Print name*) (*Signed*) (*Date*)

PERSON ADMINSTRATING INFORMED CONSENT:

____________________ ______________________ ___________

(*Print name*) (*Signed*) (*Date*)

WITNESS

Name: ______________________ Signed: _______________

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STUDY I: PROFILING DATABASE

Informed consent: Parent

I,____________________________, parent/guardian of ________________________, have read and understand the objectives and procedures of:

ANTHROPOMETRIC, MORPHOLOGICAL AND PHYSICAL PERFORMANCE DATABASE OF SOUTH AFRICAN ADOLESCENT CRICKETERS

I hereby give my consent to allow my son to participate in this research study. I have been fully informed, in writing, of the testing procedures that my son would be required to perform. By signing this document, I am agreeing that my son is able and willing to participate in this research study and acknowledge the risks associated with the nature of this sport. I have read the information sheet accompanying this form and understand it.

I have read the information sheet accompanying this form and understand it. Any questions I may have had have been answered by the researcher to my satisfaction.

PARENT (OR LEGAL REPRESENTATIVE):

____________________	_______________________	___________
(*Print name*)	(*Signed*)	(*Date*)

PERSON ADMINSTRATING INFORMED CONSENT:

____________________	_______________________	___________
(*Print name*)	(*Signed*)	(*Date*)

Department of Human Kinetics and Ergonomics

STUDY I: PROFILING DATABASE

Informed consent: Coach/Headmaster

I, ________________________, have been fully informed (both verbally and in writing) of the research titled:

ANTHROPOMETRIC, MORPHOLOGICAL AND PHYSICAL PERFORMANCE DATABASE OF SOUTH AFRICAN ADOLESCENT CRICKETERS

I hereby give my consent to allow the researcher to test measurements of my school cricket team for the above mentioned study. I have been fully informed, both verbally and in writing, of the testing procedures required for this research study. I am aware that whilst my players' anonymity will be protected at all times, the results from this research may be used for scientific or statistical purposes. By signing this document, I am agreeing to oversee the testing measurements of this research study and have been fully informed of the risks associated with my players' participation. I have been informed that my players' participation in the data collection process is voluntary, and that they may withdraw from participation at any time, without need for reason.

I have read the information sheet accompanying this form and understand it. Any questions I may have had have been answered by the researcher to my satisfaction.

COACH (OR HEADMASTER):

____________________ ______________________ ___________

(*Print name*) (*Signed*) (*Date*)

PERSON ADMINSTRATING INFORMED CONSENT:

____________________ ______________________ ___________

(*Print name*) (*Signed*) (*Date*)

WITNESS

Name: ______________________ Signed: _______________

APPENDIX B – STUDY II

Letter of information – Experimental group

Letter of information – Control group

Informed consent – Participant

Informed consent – Parent

Informed consent – Coach/Headmaster

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STUDY II: CONSTRAINTS-LED TRAINING

Letter of information: Experimental

I am a Master's student in the Department of Human Kinetic and Ergonomics (HKE) at Rhodes University. For my research project I am researching the effect of an alternative batting drill on the development of technical skill in school boy batsmen over the duration of a cricket season. Technical skill can be defined as the batsman's ability to execute a cricket stroke to the desired area in the field. The requirements of this testing procedure include participants to partake in a pre- and post-intervention testing session, as well as a six-week intervention protocol. The protocol for the pre- and post-intervention procedures and the intervention testing are similar, with batsmen required to manipulate deliveries around the playing field.

For the pre- and post-intervention testing, batsmen would face up against a ball projection machine, with the requirement to hit nine deliveries within each condition, to selected target cones placed around the inner ring. Each condition is defined by the speed (fast: $100km.h^{-1}$ and medium: $80km.h^{-1}$) and length (full: 2.5m and short: 7.5m from popping crease) of the deliveries. Each delivery is required to be hit to a specific area in the field, marked by cones. This would be performed alternatively from a leg-side target cone, to an off-side target cone starting at mid-on and ending at third-man.

For the weekly intervention protocol, batsmen would be required to manipulate deliveries from live bowlers to target areas (marked cones) around the playing field. Each week the complexity of the batting task would increase, with an emphasis on manipulation of each delivery around the playing field.

If, for any reasons, a participant wishes to withdraw from the research study they are inclined to do so.

Department of Human Kinetics and Ergonomics

STUDY II: CONSTRAINTS-LED TRAINING

Letter of information: Control

I am a Master's student in the Department of Human Kinetic and Ergonomics (HKE) at Rhodes University. For my research project I am assessing the change in technical skill of school boy cricket batsmen over the duration of a cricket season. Technical skill can be defined as a batsman's ability to execute a cricket stroke to the desired area in the field.

The requirements of this testing procedure include participants to partake in a pre- and post-season testing protocol that aims to assess the technical skill of cricket batsmen. The ability to execute a cricket stroke to the desired area in the field is termed technical skill. Therefore, by hitting specific target areas around the field, the batting protocol assesses this technical skill.

The protocol for the pre- and post-season procedures requires batsmen to face deliveries from a ball projection machine, with the objective to hit each delivery through a designated target area. The difficulty of the batting protocol would be controlled by speed and length of the deliveries. Batsmen would be required to hit nine deliveries for each of the four conditions, defined by the speed (fast: $100km.h^{-1}$ and medium: $80km.h^{-1}$) and length (full: 2.5m and short: 7.5m) of the deliveries. Each delivery is required to be hit to a specific area in the field, marked by cones. This would be performed alternatively from the leg-side targets to the off-side targets, starting with mid-on and ending with third-man. The ninth, and final, delivery in each condition is a self-selected delivery to be hit to a favoured target cone.

If, for any reasons, a participant wishes to withdraw from the research study they are inclined to do so, without need for reason.

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STUDY II: CONSTRAINTS-LED TRAINING

Informed consent: Participant

I, ________________________, have been fully informed (both verbally and in writing) of the research titled:

ASSESING CHANGES IN TECHNICAL SKILL OVER THE COURSE OF
A CRICKET SEASON

I hereby give my consent to act as a participant in the above mentioned study. I have been fully informed, both verbally and in writing, of the testing procedures required for this research study. I am aware that whilst my anonymity will be protected at all times, the results from this research may be used for scientific or statistical purposes. By signing this document, I am agreeing to participate in this research study and have been fully informed of the risks associated with my participation. I have been informed of the ability to withdraw my participation from the study at any time, without need for reason.

I have read the information sheet accompanying this form and understand it. Any questions I may have had have been answered by the researcher to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE):

____________________	______________________	___________
(*Print name*)	(*Signed*)	(*Date*)

PERSON ADMINSTRATING INFORMED CONSENT:

____________________	______________________	___________
(*Print name*)	(*Signed*)	(*Date*)

WITNESS

Name: ______________________ Signed: _______________

Department of Human Kinetics and Ergonomics

STUDY II: CONSTRAINTS-LED TRAINING

Informed consent: Parent

I,______________________________, parent/guardian of _________________________, have read and understand the objectives and procedures of:

ASSESSING CHANGES IN TECHNICAL SKILL OVER THE COURSE OF A CRICKET SEASON

I hereby give my consent to allow my son to participate in this research study. I have been fully informed, in writing, of the testing procedures that my son would be required to perform. By signing this document, I am agreeing that my son is able and willing to participate in this research study and acknowledge the risks associated with the nature of this sport. I have read the information sheet accompanying this form and understand it.

Any questions you may have can be directed at the researcher for more clarity.

PARENT/GUARDIAN (OR LEGAL REPRESENTATIVE):

____________________	_______________________	____________
(*Print name*)	(*Signed*)	(*Date*)

PERSON ADMINSTRATING INFORMED CONSENT:

____________________	_______________________	____________
(*Print name*)	(*Signed*)	(*Date*)

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STUDY II: CONSTRAINTS-LED TRAINING

Informed consent: Coach/Headmaster

I, ________________________, have been fully informed (both verbally and in writing) of the research titled:

ASSESSING CHANGES IN TECHNICAL SKILL OVER THE COURSE OF A CRICKET SEASON

I hereby give my consent to allow the researcher to test at my school cricket practices by means of measuring the technical ability of my school cricket team. I have been fully informed, both verbally and in writing, of the testing procedure required for this research study. I am aware that whilst my players' anonymity will be protected at all times, the results from this research may be used for scientific or statistical purposes. By signing this document, I am agreeing to oversee the participation of my players in this research study and have been fully informed of the risks associated with their participation. Both the players and I have been informed of the ability to withdraw their participation from the study at any time.

I have read the information sheet accompanying this form and understand it. Any questions I may have had have been answered by the researcher to my satisfaction.

SCHOOL COACH:

____________________ ______________________ ___________

(*Print name*) (*Signed*) (*Date*)

PERSON ADMINSTRATING INFORMED CONSENT:

____________________ ______________________ ___________

(*Print name*) (*Signed*) (*Date*)

WITNESS

Name: _____________________ Signed: _______________

APPENDIX C – STUDY I

Data collection sheets

DATA COLLECTION SHEET – STUDY I

Station 1

	Arms		Legs		Trunk			Shoulder			Hamstring		
Code	Upper	Lower	Upper	Lower	1	2	3	1	2	3	1	2	3
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													

Station 2

	Standing jump			Overhead throw			Side-to-side (L)			Side-to-side R		
Code	1	2	3	1	2	3	1	2	3	1	2	3
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												

Station 3

	Chest			Tricep			Subscapular			Axilla			Suprailliac			Abdominal			Thigh		
Code	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1																					
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9																					
10																					
11																					
12																					
13																					
14																					
15																					
16																					
17																					
18																					
19																					
20																					
21																					
22																					

Station 4

Code	Agility 1	Agility 2	Agility 3	Cricket Role	Y.o.B	Month	Height	Weight
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								

APPENDIX D – STUDY II

Pre-screening questionnaire

Data collection sheets

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STUDY II: CONSTRAINTS-LED TRAINING

Pre-screening questionnaire:

1. How many years have you been playing cricket for?

0 -1	2 - 4	5 - 7	8 - 10	>10

2. Have you always been a “specialized” batsman? **YES / NO**

a. How many years have you been a “specialized” batsman? ________

3. Have you ever received private coaching? **YES / NO**

a. If yes, for how many years? ________

4. Have you ever played cricket outside of school teams (i.e. National, Provincial, Club cricket)? **YES / NO**

a. If yes, at what level and for how long? ________________________

5. Is cricket your main sport? **YES / NO**

a. What other sport(s) do you play? _______________________________

b. How many afternoons a week are you busy playing sport? ____ / week

6. Are you considering making a career out of cricket? **YES / NO**

7. Have you always been a part of the ‘A team’ in your age group? **YES / NO**

a. If not, after how many years of playing cricket did you make the ‘A team’ of your specific age group? _________________

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STUDY II: CONSTRAINTS-LED TRAINING

Self-evaluation: Subjective perception

Please circle the choice that is most suited to your response:

1. How would you rate your ball-striking:

1. Very bad	2. Below average	3. Average	4. Above average	5. Very good

2. How would you rate your overall batting performance:

1. Very bad	2. Bad	3. Average	4. Good	5. Very good

3. Rate your level of frustration when you missed a target:

1. Very frustrated	2. Frustrated	3. Neutral	4. Not really bothered	5. Not frustrated at all

4. Which condition did you feel most comfortable against when manipulating the ball to specific targets:

1. Fast full (FF)	2. Fast short (FS)	3. Medium full (MF)	4. Medium short (MS)

5. Which target area do you think you were most successful with hitting across all conditions (speed and length):

1. Mid-off	2. Extra-cover	3. Cover-point	4. Third-mad
5. Mid-on	6. Mid-wicket	7. Square-leg	8. Fine-leg

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STUDY II: CONSTRAINTS-LED TRAINING

Data collection sheet:

School (Group): ________________________________

Batting position: _________

Session number: ________

Condition order: ______ - _______ - _______ - _______

Recording Sheet:

	Fast Full (FF)		**Medium Full (MF)**		**Fast Short (FS)**		**Medium Short (MS)**	
Mid-on	1	9	1	9	1	9	1	9
Mid-off	2	9	2	9	2	9	2	9
Mid-wicket	3	9	3	9	3	9	3	9
Extra-cover	4	9	4	9	4	9	4	9
Square-leg	5	9	5	9	5	9	5	9
Cover-point	6	9	6	9	6	9	6	9
Fine-leg	7	9	7	9	7	9	7	9
Third-man	8	9	8	9	8	9	8	9

Key: $\mathbf{X_4}$ – successful hit, four runs; $\mathbf{X_1}$ – successful hit, one run; **0** – unsuccessful hit

DATA SUMMARY

Successful hits		*Unsuccessful hits*	
Runs scored		*Scoring: dot balls*	
9th ball success			

APPENDIX E

Statistical results – Study I

Statistical results – Study II

STATISTICAL RESULTS – STUDY I

Statistical results: Study I

Pearson correlation matrix

Anthropometry and morphology:

Variable	Group	Stature	Mass	BMI	Body density	Body fat (%)
Group	1.000000	0.724385	0.424059	-0.008057	0.273667	-0.274322
Stature	0.724385	1.000000	0.677373	0.107076	0.132279	-0.131912
Mass	0.424059	0.677373	1.000000	0.798536	-0.465193	0.466423
BMI	-0.008057	0.107076	0.798536	1.000000	-0.740491	0.742255
Body density	0.273667	0.132279	-0.465193	-0.740491	1.000000	-0.999932
Body fat (%)	-0.274322	-0.131912	0.466423	0.742255	-0.999932	1.000000
Upper arm	0.408132	0.668686	0.532422	0.173207	0.056048	-0.053949
Lower arm	0.642058	0.804150	0.629578	0.210137	0.041937	-0.041208
Upper leg	0.558124	0.715360	0.585117	0.219960	-0.055791	0.056763
Lower leg	0.587804	0.735667	0.508843	0.109394	0.151651	-0.150324
Trunk	-0.259528	-0.207556	-0.051487	0.087836	-0.095102	0.095702
Shoulder	-0.121063	-0.177483	-0.204132	-0.139154	0.116355	-0.116426
Hamstring	-0.176477	-0.188375	-0.064760	0.065561	0.057652	-0.057438
Agility	-0.442864	-0.284937	0.018512	0.248392	-0.359488	0.361451
Standing jump	0.621865	0.521921	0.067413	-0.327803	0.539009	-0.539358
Overhead throw	0.668226	0.722019	0.711357	0.371322	-0.030256	0.029700
Rotational throw: left	0.637214	0.582081	0.553281	0.280100	0.023967	-0.024462
Rotational throw: right	0.620561	0.609605	0.583647	0.295872	-0.001640	0.001475

Anthropometry:

Variable	Upper arm	Lower arm	Upper leg	Lower leg
Group	0.408132	0.642058	0.558124	0.587804
Stature	0.668686	0.804150	0.715360	0.735667
Mass	0.532422	0.629578	0.585117	0.508843
BMI	0.173207	0.210137	0.219960	0.109394
Body density	0.056048	0.041937	-0.055791	0.151651
Body fat (%)	-0.053949	-0.041208	0.056763	-0.150324
Upper arm	1.000000	0.462237	0.412825	0.606387
Lower arm	0.462237	1.000000	0.726643	0.687566
Upper leg	0.412825	0.726643	1.000000	0.501247
Lower leg	0.606387	0.687566	0.501247	1.000000
Trunk	-0.224265	-0.153144	-0.072868	-0.166106
Shoulder	0.000573	-0.187404	-0.170564	-0.044031
Hamstring	-0.124876	-0.195259	-0.310555	-0.232155
Agility	-0.173386	-0.121609	-0.040844	-0.209447
Standing jump	0.222702	0.361943	0.307374	0.326738
Overhead throw	0.590534	0.602690	0.443783	0.533319
Rotational throw: left	0.189551	0.632659	0.568772	0.393657
Rotational throw: right	0.213766	0.655437	0.580931	0.425125

Flexibility and agility:

Variable	Trunk	Shoulder	Hamstring	Agility
Group	-0.259528	-0.121063	-0.176477	-0.442864
Stature	-0.207556	-0.177483	-0.188375	-0.284937
Mass	-0.051487	-0.204132	-0.064760	0.018512
BMI	0.087836	-0.139154	0.065561	0.248392
Body density	-0.095102	0.116355	0.057652	-0.359488
Body fat (%)	0.095702	-0.116426	-0.057438	0.361451
Upper arm	-0.224265	0.000573	-0.124876	-0.173386
Lower arm	-0.153144	-0.187404	-0.195259	-0.121609
Upper leg	-0.072868	-0.170564	-0.310555	-0.040844
Lower leg	-0.166106	-0.044031	-0.232155	-0.209447
Trunk	1.000000	0.334245	0.117698	0.144579
Shoulder	0.334245	1.000000	0.217199	-0.007308
Hamstring	0.117698	0.217199	1.000000	-0.090765
Agility	0.144579	-0.007308	-0.090765	1.000000
Standing jump	-0.097851	-0.008955	-0.023214	-0.559063
Overhead throw	-0.146850	-0.118167	0.056167	-0.381039
Rotational throw: left	-0.028253	-0.156382	-0.035820	-0.310859
Rotational throw: right	-0.008154	-0.202859	-0.039830	-0.305709

Power:

Variable	Standing jump	Overhead throw	Rotational throw: left	Rotational throw: right
Group	0.621865	0.668226	0.637214	0.620561
Stature	0.521921	0.722019	0.582081	0.609605
Mass	0.067413	0.711357	0.553281	0.583647
BMI	-0.327803	0.371322	0.280100	0.295872
Body density	0.539009	-0.030256	0.023967	-0.001640
Body fat (%)	-0.539358	0.029700	-0.024462	0.001475
Upper arm	0.222702	0.590534	0.189551	0.213766
Lower arm	0.361943	0.602690	0.632659	0.655437
Upper leg	0.307374	0.443783	0.568772	0.580931
Lower leg	0.326738	0.533319	0.393657	0.425125
Trunk	-0.097851	-0.146850	-0.028253	-0.008154
Shoulder	-0.008955	-0.118167	-0.156382	-0.202859
Hamstring	-0.023214	0.056167	-0.035820	-0.039830
Agility	-0.559063	-0.381039	-0.310859	-0.305709
Standing jump	1.000000	0.478659	0.507867	0.515168
Overhead throw	0.478659	1.000000	0.657714	0.676966
Rotational throw: left	0.507867	0.657714	1.000000	0.927875
Rotational throw: right	0.515168	0.676966	0.927875	1.000000

Independent t-test results:

Variable	T-tests; Grouping: GRP (STUDY I - SPREADSHEET) Group 1: 1 Group 2: 2										
	Mean	Mean	t-value	df	p	Valid N	Valid N	Std.Dev.	Std.Dev.	F-ratio	p
Age	14.860	12.375	22.71956	88	0.000000	50	40	0.35051	0.66747	3.626267	0.000027
Stature	1725.000	1559.000	9.46109	88	0.000000	50	40	74.40238	92.09248	1.532056	0.156976
Mass	61.580	50.783	4.39922	88	0.000030	50	40	8.89834	14.23311	2.558480	0.002012
BMI	0.207	0.207	0.03815	88	0.969657	50	40	0.02826	0.04330	2.347202	0.004949
Body density	1.082	1.076	2.88570	88	0.004911	50	40	0.00908	0.01263	1.935308	0.029080
Body fat (%)	7.407	10.248	-2.88502	88	0.004921	50	40	3.87839	5.45056	1.975054	0.024522
Upper arm	31.240	28.650	4.39147	88	0.000031	50	40	2.72973	2.84244	1.084287	0.781752
Lower arm	26.320	23.350	8.20897	88	0.000000	50	40	1.64677	1.77663	1.163938	0.609974
Upper leg	42.280	38.425	5.96833	88	0.000000	50	40	2.75563	3.37325	1.498504	0.179466
Lower leg	41.580	37.875	7.20883	88	0.000000	50	40	2.34816	2.51343	1.145711	0.646823
Trunk	20.760	23.750	-2.21152	88	0.029591	50	40	6.41923	6.31543	1.033143	0.924134
Shoulder	40.460	43.925	-1.27561	88	0.205451	50	40	10.24239	15.43288	2.270342	0.006883
Hamstring	43.960	70.550	-1.77751	88	0.078940	50	40	79.30925	57.60162	1.895738	0.041087
Agility	17.238	18.844	-4.88842	88	0.000005	50	40	1.64906	1.41049	1.366892	0.315157
Standing jump	1.989	1.659	7.38901	88	0.000000	50	40	0.19260	0.23041	1.431256	0.233595
Overhead throw	6.307	4.559	8.13797	88	0.000000	50	40	1.07133	0.93295	1.318637	0.374213
Rotational throw: left	7.924	5.288	7.57272	88	0.000000	50	40	1.74927	1.49415	1.370639	0.310930
Rotational throw: right	7.693	5.175	7.09280	88	0.000000	50	40	1.74682	1.57741	1.226321	0.513254

STATISTICAL RESULTS – STUDY II

Statistical results: Study II

Pre- and post-test ANOVA:

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	966.8865	1	966.8865	71.65224	0.000001
GROUP	14.6365	1	14.6365	1.08466	0.315311
Error	188.9182	14	13.4942		
TEST	0.0751	1	0.0751	0.00603	0.939185
TEST*GROUP	19.7626	1	19.7626	1.58686	0.228371
Error	174.3545	14	12.4539		
SPEED	85.3161	1	85.3161	8.02362	0.013298
SPEED*GROUP	15.0036	1	15.0036	1.41102	0.254649
Error	148.8636	14	10.6331		
LENGTH	45.9888	1	45.9888	3.82805	0.070652
LENGTH*GROUP	0.2388	1	0.2388	0.01988	0.889893
Error	168.1909	14	12.0136		
TEST*SPEED	7.9786	1	7.9786	1.07132	0.318196
TEST*SPEED*GROUP	0.1036	1	0.1036	0.01390	0.907809
Error	104.2636	14	7.4474		
TEST*LENGTH	2.0115	1	2.0115	0.17392	0.682974
TEST*LENGTH*GROUP	5.0740	1	5.0740	0.43872	0.518499
Error	161.9182	14	11.5656		
SPEED*LENGTH	24.4638	1	24.4638	3.73938	0.073622
SPEED*LENGTH*GROUP	8.5263	1	8.5263	1.30327	0.272767
Error	91.5909	14	6.5422		
TEST*SPEED*LENGTH	0.1945	1	0.1945	0.03354	0.857317
TEST*SPEED*LENGTH*GROUP	7.3195	1	7.3195	1.26240	0.280095
Error	81.1727	14	5.7981		

Pre-test ANOVA:

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	134.4388	1	134.4388	63.24786	0.000000
GRP	3.2975	1	3.2975	1.55132	0.226659
Error	44.6373	21	2.1256		
SPEED	3.3678	1	3.3678	3.03098	0.096322
SPEED*GRP	0.4982	1	0.4982	0.44837	0.510406
Error	23.3333	21	1.1111		
LENGTH	5.2474	1	5.2474	2.68788	0.116010
LENGTH*GRP	0.4539	1	0.4539	0.23252	0.634652
Error	40.9972	21	1.9522		
TARGET	11.6133	7	1.6590	1.79544	0.092258
TARGET*GRP	2.1024	7	0.3003	0.32504	0.941662
Error	135.8324	147	0.9240		
SPEED*LENGTH	0.0371	1	0.0371	0.04409	0.835702
SPEED*LENGTH*GRP	2.2544	1	2.2544	2.68269	0.116342
Error	17.6477	21	0.8404		
SPEED*TARGET	7.4014	7	1.0573	0.89424	0.512772
SPEED*TARGET*GRP	5.6187	7	0.8027	0.67886	0.689738
Error	173.8106	147	1.1824		
LENGTH*TARGET	1.9015	7	0.2716	0.28884	0.957476
LENGTH*TARGET*GRP	13.2602	7	1.8943	2.01427	0.056975
Error	138.2453	147	0.9404		
SPEED*LENGTH*TARGET	4.9501	7	0.7072	0.68775	0.682278
SPEED*LENGTH*TARGET*GRP	4.0805	7	0.5829	0.56694	0.781843
Error	151.1477	147	1.0282		

Post-test ANOVA:

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	492.0045	1	492.0045	41.68383	0.000015
GROUP	0.1920	1	0.1920	0.01627	0.900314
Error	165.2455	14	11.8032		
SPEED	72.7375	1	72.7375	10.86793	0.005297
SPEED*GROUP	8.8000	1	8.8000	1.31483	0.270742
Error	93.7000	14	6.6929		
LENGTH	33.6182	1	33.6182	5.12239	0.040039
LENGTH*GROUP	1.5557	1	1.5557	0.23704	0.633887
Error	91.8818	14	6.5630		
SPEED*LENGTH	14.5102	1	14.5102	2.00285	0.178862
SPEED*LENGTH*GROUP	15.8227	1	15.8227	2.18401	0.161593
Error	101.4273	14	7.2448		

Target ANOVA:

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	537.7551	1	537.7551	63.24786	0.000000
GROUP	13.1899	1	13.1899	1.55132	0.226659
Error	178.5492	21	8.5023		
FRONT/BA	19.8750	3	6.6250	1.83764	0.149404
FRONT/BA*GROUP	3.0489	3	1.0163	0.28190	0.838268
Error	227.1250	63	3.6052		
LEG/OFF	0.1291	1	0.1291	0.03128	0.861322
LEG/OFF*GROUP	0.0422	1	0.0422	0.01021	0.920465
Error	86.6970	21	4.1284		
FRONT/BA*LEG/OFF	26.4489	3	8.8163	2.42009	0.074321
FRONT/BA*LEG/OFF*GROUP	5.3185	3	1.7728	0.48665	0.692780
Error	229.5076	63	3.6430		

<u>Intra-class correlation</u>:

Pair of Variables		Valid N	Spearman R	t(N-2)	p-value
FF1	**& FF2**	16	-0.297050	-1.16400	0.263877
FF1	& FS2	16	-0.110341	-0.41539	0.684150
FF1	& MF2	16	-0.115125	-0.43364	0.671157
FF1	& MS2	16	-0.223859	-0.85941	0.404589
FF1	& TOT2	16	-0.238117	-0.91734	0.374499
FS	& FF2	16	0.121634	0.45852	0.653617
FS	& FS2	16	0.251342	0.97163	0.347726
FS	& MF2	16	0.352274	1.40837	0.180840
FS	& MS2	16	-0.205128	-0.78420	0.445991
FS	& TOT2	16	0.109286	0.41137	0.687026
MF1	& FF2	16	0.185063	0.70461	0.492607
MF1	& FS2	16	-0.138143	-0.52189	0.609908
MF1	& MF2	16	-0.384737	-1.55960	0.141168
MF1	& MS2	16	0.322202	1.27348	0.223585
MF1	& TOT2	16	-0.007543	-0.02822	0.977883
MS1	& FF2	16	0.371749	1.49834	0.156251
MS1	& FS2	16	0.205679	0.78639	0.444744
MS1	& MF2	16	0.126719	0.47799	0.640034
MS1	& MS2	16	0.373876	1.50830	0.153711
MS1	& TOT2	16	0.399753	1.63179	0.125005
TOT1	& FF2	16	0.136906	0.51712	0.613142
TOT1	& FS2	16	-0.038383	-0.14372	0.887769
TOT1	& MF2	16	-0.035184	-0.13173	0.897075
TOT1	& MS2	16	0.030553	0.11437	0.910567
TOT1	& TOT2	16	0.017012	0.06366	0.950139

<u>Portus *et al*. (2010) results</u>:

Table 4: Statistical comparisons and discriminant analysis results for batting skills test results by pathway group

Variable	Group 1 Elite	Group 2 Emerging	Group 3 Junior	F	P	Scheffe post hoc	Blocked Discriminant Analysis Variables	Cross Validated Classification Rate	Stepwise Discriminant Analysis Variables	Cross Validated Classification Rate
Total 110 km/h[a]	21.78±7	17.04±7.87	14.89±5.85	11.343	<.01	1v2 (.01) 1v3 (<.01) 2v3 (.02)	1	59.2%		
Total Good Length 110km/h	7.04±3.57	4.56±3.55	3.88±3.24	8.814	<.01	1v2 (<.01) 1v3 (<.01)	2			
Total Short130km/h	7.61±3.64	5.42±3.85	4.72±3.37	6.652	<.01	1v2 (.01) 1v3 (<.01)	3			
Total 130km/h	15.8±6.35	12.93±6.64	10.6±5.91	8.448	<.01	1v3 (<.01) 2v3 (.01)	4			
Total Legside	14.13±6.98	11.34±6.06	8.98±5.01	10.07	<.01	1v3 (<.01) 2v3 (<.01)				
Total Offside	23.44±7.03	18.63±8.56	16.51±6.99	8.199	<.01	1v2 (.01) 1v3 (<.01)	5			
Total Full Length	10.04±4.46	9.43±5.6	7.54±4.48	5.209	<.01	2v3 (.01)	6			
Total Short Length	16.96±6.63	12.54±6.46	11.3±5.52	8.84	<.01	1v2 (<.01) 1v3 (<.01)	7			
Total Mid Off	6.82±3.77	4.85±3.65	4.58±3.26	4.345	.01	1v2 (.03) 1v3 (.02)	8			
Total Backward Point	6.5±2.88	4.73±3.48	4.22±3.4	4.748	.01	1v2 (.04) 1v3 (.01)	9			
Total Wide Mid-On	7.15±4.09	5.07±3.68	4.31±3.63	6.350	<.01	1v2 (.02) 1v3 (<.01)	10			
Total 4's Hit[a]	6.85±2.4	5.3±2.75	4.51±2.12	10.932	<.01	1v2 (.01) 1v3 (<.01) 2v3 (.02)	11		1	62.1%
Total Score[a]	37.57±10.28	29.97±12.01	25.49±9.11	16.219	<.01	1v2 (<.01) 1v3 (<.01) 2v3 (<.01)			2	

[a] Data for these variables violated homogeneity of variance assumption so Borwn-Forsythe F and Tamhane T2 post hoc are presented.