THE EFFECTS OF FOUR-WEEK RESISTANCE TRAINING ON CRICKET BOWLING VELOCITY

by

RIFQAH MAKER

Thesis submitted in fulfilment of the requirements for the degree

Master of Technology in Sports Management

in the Faculty of Business and Management Sciences
at the Cape Peninsula University of Technology

Supervisor: Dr. M.S. Taliep

District Six Campus
November 2019

DECLARATION

I, Rifqah Maker, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

12 – 11 – 2019

Signed **Date**

ABSTRACT

Background: Sports at various levels are often performed at high speeds. This is evident in several sports ranging from non-ball sports like athletics to ball sports like baseball, tennis and cricket. The ability to generate high speeds has advantages in many sports as it gives the opposition less time to react. In cricket bowling, the ball release speed has a significant influence on the outcome of the delivery. A faster delivery reduces the batter's decision-making time and stroke-execution time and therefore increases the chance of him or her making a mistake and being dismissed. This increased velocity can be achieved through resistance training in bowlers. Resistance training enables an athlete to increase their overall strength and develop their power. This kind of training should be characterised by specificity as well as progressive overload. This can be done by performing bowling training (specific resistance) while implementing a progressive overload in the number of deliveries bowled and/or the number of repetitions and sets performed in general and special resistance training.

Evidence suggests that these resistance training methods can lead to a significant increase in bowling velocity in cricket within a reasonable time frame. However, most programmes require specialised equipment or access to a gym, which can be quite expensive. They can also be very time-consuming.

At the elite level, cricket players have access to physical trainers and physical training resources, and their time can be dedicated to performance enhancement. However, at an amateur club level this will probably not be the case. Recreational players are less likely to have the time available to do extra training at gym while others simply may not have the financial resources to join a gym. Therefore, in order to optimise training for amateur club players and coaches, finding a resistance training programme that can be used during practice sessions would be ideal. This resistance training should incorporate strength, power and cricket-specific training.

Aims and objectives: The primary aim of this study was to develop and examine an appropriate resistance training programme to improve bowling velocity in amateur club cricket fast bowlers. This was done in two parts: first, an attempt was made to determine if amateur club level players have the time and resources to perform extra training to facilitate an increase in bowling velocity. This was achieved through a questionnaire. The objectives of the questionnaire were to identify the accessibility of resistance training in-season and identify whether players have the time to perform additional training outside of their normal training hours. The second part of the study sought to develop a time- and cost-effective training programme that amateur club-level players can use to improve their bowling velocity. Additionally, the programme had to be performed during training with minimal disruption to the normal training session, and it should not pose any risk of injury to the players. An assessment of the effects of this study was done.

Methods: The questionnaire was sent out to senior club fast bowlers (1st and 2nd division) at various cricket clubs as well as distributed online for the participants to complete. The questionnaire aimed at acquiring information about the bowler's cricket training and strength training load during the cricket season. It also retrieved demographic and injury information as well as their perception of the importance of strength and power training. Further, participants were required to state whether they had personally implemented training that contributed to an improvement in their bowling velocity and if they had a gym membership. The questionnaire was also used to determine whether players at club level had the time and financial resources to perform additional strength or power training (outside of their normal cricket training hours) that could produce an improvement in their bowling performance.

The second part of the study was the development and implementation of the training programme, and assessment of its effects. Twenty participants were recruited and randomly assigned to an experimental (n = 11) and control (n = 9) group. Of these participants, 9 of the experimental and 9 of the control group completed the trial. The experimental group was required to perform the training programme for four weeks. This programme consisted of a combination of general, special, and specific resistance training. All special resistance exercises were done with a 3kg medicine ball. Additionally, participants were required to perform 24-30 deliveries each session with an overweighted, underweighted and regular cricket ball. On the other hand, the control group was requested not to participate in any strength training during this period and only perform their normal cricket training sessions.

All participants' performance was measured through a testing protocol which took place at baseline, two weeks and four weeks after training. The variables measured included bowling velocity, bowling accuracy, upper body power and lower body power.

Results: The results of the questionnaire showed that many amateur club-level cricketers were not able to perform additional training at home or at gym, despite their knowing how important strength and power training is for improving their bowling performance. This was mainly due to players stating that they do not have the time or financial resources to do so.

Results of the testing protocol for the experimental group revealed significant increases in bowling velocity between the baseline test and two weeks of training (4.1km/h, $p = 0.003$) and between the baseline test and four weeks of training (5.1km/h, $p < 0.001$). This equates to a final 6% increase across the four weeks. This increase in bowling speed was not at the cost of bowling accuracy as there were no significant differences in bowling accuracy across the four weeks. There was also no significant difference in the upper body power and leg power across the four weeks. The control group showed no significant differences in bowling velocity, bowling accuracy or lower body power across the four weeks. However, there was a significant increase in upper body power in the control group across the four weeks.

Conclusion: Utilising only a four-week resistance training programme – consisting of a combination of core and lower body exercises (squats, lunges, step ups) as well as cricket-specific plyometric exercises and weighted implement training – significantly increased bowling velocity by 6%. This had no negative effect on the accuracy of the deliveries and posed no risk of injury to players. It would therefore be advantageous for club level bowlers to utilise this programme during training sessions to improve their bowling performance. Recommendations have been provided for this.

ACKNOWLEDGEMENTS

I wish to thank:

Dr. Sharhidd Taliep, for his patience and commitment in helping me achieve this milestone;

The staff of the Sports Department at Cape Peninsula University of Technology for their constant support;

The participants and my assistants in this study;

Sports Science Institute of South Africa, for allowing me to use their equipment and facilities;

The financial assistance of the National Research Foundation towards this research is acknowledged. Opinions expressed in this thesis and the conclusions arrived at are those of the author, and are not necessarily to be attributed to the National Research Foundation.

DEDICATION

Firstly, I dedicate this thesis to my parents, for your patience, encouragement and support throughout my studies and throughout this milestone: you were a source of strength through everything. The sacrifices you made for me to be where I am today will never be lost on me. Your love, kindness and selflessness were everything I needed to help me continue my studies.

Secondly, to my brothers, for always making my workload seem lighter through jokes and laughter. You, unconsciously, gave me the confidence to complete this chapter of my life.

Finally, to my supervisor, Dr Sharhidd Taliep, for allowing me the perfect balance of freedom and guidance to learn and implement everything you have taught me. Thank you for the countless hours of support, constructive criticism and patience you gave me throughout this journey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Open kinetic chain	Exercises that are performed where the hands or feet are free to move
Closed kinetic chain	Exercises that are performed where the hands or feet are fixed and cannot move
Individualized dynamic variable resistance (IDVR)	Exercises that train your muscles to work at maximum speed throughout each repetition
Isokinetic	Exercises done at a constant speed
Recreational	Participants playing at club level or recreationally
Skilled	Participants playing at provincial or college level
Highly-skilled	Participants playing at elite level
Repetition maximum (RM)	The most weight you can lift for a number of exercise movements
Maximal voluntary contraction (MVC)	A standardised method for measurement of muscle strength
Knee flexion	The decreased angle (bending movement) between the limbs at the knee joint
Knee extension	The increased angle (straightening movement) between the limbs at the knee joint
Repetitions (reps)	The number of times you perform a specific exercise
Sets	The number of cycles of repetitions that you complete

CHAPTER OUTLINES

Chapter One provides an overview of the study: background, aims and objectives, research design and methodology, data collection methods, and data analysis.

Chapter Two offers a review of the literature that focuses specifically on resistance training to increase throwing velocity in various sports and the bowling velocity of cricket players.

Chapter Three describes the methodology of the study, along with a description and rationale for the sample population and the instruments used to obtain data.

Chapter Four presents the results of the questionnaires and the experimental trial.

Chapter Five discusses the results of the questionnaires and testing protocols.

Chapter Six concludes the study with an overview of its results, acknowledges its limitations, and makes recommendations for further research aimed at improving player performance.

CHAPTER ONE

INTRODUCTION

1.1. Background to the research problem

A variety of sports are performed at high speeds, ranging from non-ball sports like athletics to various ball sports, like baseball, tennis and cricket. Skilled performances by the best athletes are characterised by their generation of fast speeds. This includes the fastest 100m sprint by Usain Bolt (Larsson, 2018), the fastest baseball pitch by Aroldis Chapman (Guinness World Records, 2018), the fastest serve in tennis by Samuel Groth (Tennis Companion, 2018) or the fastest ball bowled in cricket by Shoaib Akhtar (Total Sportek, 2017). The ability to generate these high speeds has the advantage in certain competitive sports of giving the opposition less time to react. In cricket bowling, the ball release speed has a significant influence on the outcome of the delivery where a faster delivery reduces the batter's decision-making time and stroke-execution time, and therefore increases the chance of the batter's making a mistake and being dismissed (Wickington & Linthorne, 2017).

In sports such as baseball (pitching), and cricket (bowling), enhancing throwing/bowling velocity is thus of utmost importance (Escamilla et al., 2000; Feros et al., 2019). Throwing velocity can be increased by improving the throwing biomechanics and through resistance training (DeRenne et al., 2001). Resistance training allows an athlete to increase their overall strength and develop their power (Szymanski et al., 2009). Szymanski (2012) adds that the resistance training should focus on sport-specific training as well as progressive overload.

There was no study that used a combined resistance training programme that found an increase in velocity and no decrease in accuracy. Therefore, this study will focus on the use of combined general, special and weighted implement resistance training methods to help increase bowling velocity in cricket.

1.2. Statement of the research problem

Cricket managers, coaches and fast bowlers are always trying to find ways of increasing bowling velocity. It would appear that very few studies have investigated this. Elite cricket players have access to physical trainers and resources, and their time is dedicated to performance enhancement. However, at an amateur club level this is probably not the case. It is important to identify what training strategies amateur fast bowlers can utilise to improve their bowling velocity, as this has not been previously reported in the literature. This is important simply because a faster ball delivery has a significant outcome and can potentially increase the chance of the batter being dismissed (Wickington & Linthorne, 2017). Furthermore, in order to optimise training for amateur players and coaches, finding a resistance training programme that can be used during practice sessions would be ideal. This resistance training should incorporate strength, power and cricket-specific training.

1.3. Aims and objectives of the study

The aim of this study was to develop a resistance training programme appropriate for club cricket fast bowlers and to examine whether it improved bowling velocity.

1.3.1. General aims and specific objectives

Questionnaire

The aim of the questionnaire was to determine if amateur club-level players have the time and resources to perform extra training to facilitate an increase in bowling velocity. The objectives of the questionnaire were to identify players' willingness to engage in resistance training in season and identify whether players have the time to perform additional training outside of their normal training hours

Development of resistance training programme

The aim was to develop a time and cost-effective training programme that amateur club-level players can use to increase their bowling speed. The objective was to develop a training programme that is effective in terms of time and cost. Additionally, there was a pragmatic requirement that this programme ought to be easily integrated within in-training with little or no disruption to the normal training session and pose no risk of injury to the players.

Assessment of resistance training programme

The aim of this was to assess the effectiveness of the selected resistance training programme. The aims of the assessment were to identify any significant change in bowling velocity, bowling accuracy, upper body power and lower body power, across 4 weeks of resistance training. A further objective was to identify whether there were inter-variable relationships between bowling velocity and the other measured factors.

1.4. Data analysis

Data obtained from the questionnaire data is reported in percentages and absolute values where appropriate. Mean ± standard deviations of the descriptive data, fitness characteristics and bowling performance were calculated. For the experimental trial, the measurements of the experimental and control groups were compared using a General Linear Model. When significant differences were found, a post-hoc Bonferroni analysis was performed to determine where the differences were. Statistical significance was considered when $P < 0.05$. Furthermore, Spearman's rank order was performed to determine correlations between ball velocity and other variables measured, as well as between ball accuracy and throw distance.

CHAPTER TWO

LITERATURE REVIEW

This chapter will describe the method of literature collection and selection. It will identify methods of resistance training that can be used to increase ball velocity in various ball sports. These methods include general, special, and specific resistance training. A summary of these different training methods is made, and certain hypotheses are postulated for the experimental trial.

2.1. Literature collection and selection

To ensure the quality of the work reviewed, peer-reviewed journal articles were collected. The search strategy conducted made use of five online databases: EBSCOHost, SportsDiscus, ResearchGate, PubMed and Google Scholar. These databases were searched from April 2015 to August 2019, using different combinations of the following words: general resistance, special resistance, specific resistance, weighted, modified, implement training, overweighted, underweighted, bowling, throwing, velocity, accuracy, cricket, pitching, baseball, and handball. Reference lists in these articles and suggestion lists on these databases were scanned to find other relevant articles. When relevant material was found, it was required to meet the following criteria: it had to focus on the use of different resistance training methods to increase bowling or throwing velocity and had to be written in English. There were no restrictions on the year of publication, type of sport reported, or age, gender, and player level. Based on these criteria, and according to their titles, abstracts and keywords, 107 journal articles were retrieved for inclusion in this study and read in full text. Additionally, various books, websites, and recommended training programmes were consulted in cases where relevant journal articles could not be found. Due to the limited amount of research on resistance training in cricket bowling, sports that utilised an action closely related to bowling (such as baseball and handball) are often featured in the literature review.

There have been few studies which have found an increase in ball release velocity in cricket pace bowlers following a resistant training programme. In cricket pace bowling, faster ball speeds have been related to both, upper body and to a lesser extent lower body power (Pyne et al., 2006; Wormgoor et al., 2010). The force production of the upper body during the bowling stride in particular, accounts for a large part of the variance of bowling velocity (M. Portus et al., 2000; Pyne et al., 2006). During the bowling stride, large ground reaction forces have to be absorbed at front foot landing and powerful deliveries can be generated through the leg extension, hip rotation, trunk flexion and shoulder rotation (M. Portus et al., 2000). Additionally, the stop-start nature of sprinting in fast bowling during the ‘run-up’ and delivery of the ball are a contributor of stress for fast bowlers which could affect their overall bowling performance (Noakes & Durandt, 2000). Therefore, a substantial amount of muscle strength is needed to cope with this load as well as reduce muscle damage (Noakes & Durandt, 2000). As a result, strengthening both the upper and lower body through resistance training could potentially result in an increase in ball release velocity. Resistance training used to improve ball velocity in a number of sports can be broadly categorised into three types. This includes, general, special and specific resistance training.

2.2. General resistance training

Fleck & Kraemer (2014) define general resistance training as a type of exercise that requires the body’s muscles to move or attempt to move against an external opposing force. It is designed to increase overall strength by using traditional exercises (Szymanski et al., 2009) as well as muscle contractile capabilities (Szymanski, 2007). General resistance training is synonymous with the term strength training. These traditional strength training exercises include exercises with typical gym equipment and can include the use of free weights (Newton & McEvoy, 1994; Prokopy et al., 2008), weighted machines (Bloomfield et al., 1990; Gorostiaga et al., 1999; Hermassi et al., 2010; Hermassi et al., 2011), or specialised machines (Wooden et al., 1992; Davison et al., 2010). One can also use one’s own bodyweight (Prokopy et al., 2008; Manchado et al., 2017), or elastic tubing (Escamilla et al., 2012).

General resistance training and its effects on velocity have been extensively studied, and there are a number of good review articles discussing this topic (Szymanski et al., 2009; Van den Tillaar, 2004; Szymanski, 2012). Overall, the evidence suggests that effective strength training can significantly improve velocity in several different sporting codes, including throwing velocity in handball (Hermassi et al., 2010; Hermassi et al., 2011; Gorostiaga et al., 1999), baseball (Newton & McEvoy, 1994; Wooden et al., 1992), water polo (Bloomfield et al., 1990) and softball (Prokopy et al., 2008). Very little literature exists that investigates the effects of general strength training on cricket bowling velocity. Studies of the effects of general strength training on throwing velocity were reviewed because bowling is an activity closely related to throwing. Using bodyweight exercises, or free weights, or a combination of free weights and weighted machines, have been shown to result in an increase in throwing velocity in various sports. The use of specialised fitness machines and a combination of the various methods gave similar results.

2.2.1. Bodyweight exercises

Bodyweight exercises are exercises that utilise the participant's own body weight. They have been found to improve throwing velocity in handball (Manchado et al., 2017) and softball players (Prokopy et al., 2008).

Manchado et al. (2017) performed core training on junior and senior recreational handball players. In this study, seven different exercises were used that focused on improving the kinetic chain of movement involved in the throwing action. These exercises focused on the rectus abdominis (one exercise for the lower part, two for the middle part, and two for the upper part) and two exercises for the lumbar and gluteal muscles. The exercises were performed by the experimental group with the progressive overload being quantified using the objective load equivalents method over 10 weeks. Additional stability exercises were done from the fourth week onward. On the other hand, the control group performed only their regular handball training sessions. The authors found that after progressively overloading the participants over 10 weeks (three times a week), throwing velocity increased by 3.4 km/h while the control group showed no change. The advantage of this type of training is that the only equipment needed is a Swiss Ball for the stability exercises, and participants can incorporate it into their regular training sessions. However, using this type of core training alone only resulted in a 3.4km/h increase over 10 weeks.

Prokopy et al. (2008) used bodyweight exercises to try and improve throwing velocity in female softball players. Skilled female softball players were placed in a closed kinetic chain group. Close kinetic chain resistance exercises consist of exercises or movements where the distal part of the working limb is fixed and cannot be moved. For 12 weeks, this group used Redcord mini-trainers (ropes with handles that can be height adjusted) hanging from power racks to perform the required exercises, with their own bodyweight as resistance. The results indicated a small but significant increase of 3.2 km/h in throwing velocity after the 12 weeks. These two studies using bodyweight exercises therefore showed a small increase in throwing velocity (approximately 3km/h) after a fairly long period of time (10-12 weeks).

A bodyweight training programme has also been recommended by the South African national cricket team trainer, Greg King (Cricket Lab, 2016). These exercises include variations of squats, hip raises, push-ups and pull-ups. It was recommended that the programme be followed three times a week for 3-4 weeks. Once completed, players would then progress to the next level programme, which includes squats, lunges, step-ups, hip raises, push-ups and pull-ups. However, the effectiveness of these programmes in improving bowling velocity has not been established.

2.2.2. Free weights and weight machines

The use of free weights and weight machines was also found to improve throwing velocity in softball (Prokopy et al., 2008; Hermassi et al., 2010; Hermassi et al., 2011), baseball (Newton & McEvoy, 1994), and handball (Gorostiaga et al., 1999). Free weights are weights that are not attached to another structural device, and can include dumbbells and barbells. On the other hand, weight machines are exercise machines with weights attached used for weight training. This can include seated leg press or Smith machine bench press.

One of the most significant improvements in throwing velocity after resistance training was found in highly skilled handball players after 10 weeks. The average age of these players was 20. Hermassi et al. (2010) recorded a 22.3km/h increase in throwing velocity (throw with a run-up) using heavy resistance training (80-90% of 1RM) and a 19.8km/h increase when using a moderate resistance (55-75% of 1RM) training method. The exercises performed were bench presses and pull-overs. There was no significant difference in throwing velocity in the control group which received no resistance training. Interestingly, a similar 22.3km/h increase in throwing velocity was obtained in the heavy resistance training group when the study was repeated over eight weeks (Hermassi 2011). The only difference in the exercises was that in 2011, the authors added half back squats to the heavy resistance training protocol. This shows that by having an additional exercise in the programme to ensure that the programme targets the major muscles of the body, one is able to increase throwing velocity by the same amount in a shorter period of time. These results were not replicated when using adolescent handball players (mean age of 15) Gorostiaga et al. (1999). The authors only found a 2.3km/h increase in throwing velocity after 6 weeks of heavy resistance training. The different result can be attributed to differences in the age of the participants and the duration of the training. In particular, adolescent players' neuromuscular response to heavy resistance training might be different from that of adults (National Council on Strength and Fitness, 2015).

In softball, general resistance training was found to show only minimal improvement in throwing velocity. Skilled players were placed into two different groups, an open kinetic chain group and a closed kinetic chain group (Prokopy et al., 2008). The open kinetic chain group performed various open kinetic chain exercises which allow the hands and feet to move. For this 12-week programme, participants used free weights to perform bench press, bent-over row, lat pulldown, straight arm pull down, internal/external rotation, biceps curl, tricep extensions, and shoulder press. Results of this study showed no change in throwing velocity for the open kinetic chain group whereas the closed kinetic chain group increased their throwing velocity by 3.2km/h. The authors have attributed the difference in increases to the nature of the equipment that was used. The possible increase in eccentric load during the closed kinetic chain exercises improved shoulder and torso stability resulting in an improvement in throwing velocity (Prokopy et al., 2008). Furthermore, a possible reason for the small increase in the closed kinetic chain and no significant increase in the open kinetic chain group over such a long period (12 weeks), can be due to the participants being skilled players. It has been shown that highly skilled players will be less affected by training than recreational athletes, since the former are already receiving extensive resistance training and have less potential for power enhancement (Lin & Chang, 2008).

In baseball, one of the few studies conducted found that the use of free weights increased throwing velocity (Newton & McEvoy, 1994). Highly skilled junior players were divided into two groups, a weight training group and a control group. In addition to normal baseball training, the weight training group performed upper body weight training which consisted of three sets of six to ten reps of barbell bench press and barbell pullover exercises, twice a week. The control group only participated in normal baseball training sessions. The programme lasted a total of eight weeks. Upon completion, the results indicated a significant mean increase of 4.7km/h in throwing velocity for the weight training group, with no change for the control group.

Although all these studies mentioned above reported an increase in throwing velocity after their respective training programmes, a study conducted by Bloomfield et al. (1990) showed conflicting results. For this study, an 8-week, 3 times-a-week progressive intervention strength training programme for highly skilled water polo players was developed. This emphasised upper body strength development by performing overhead deltoid press, behind the head press, pull-overs, pulldowns, decline press, Nautilus fly, bicep curls and tricep press at 50-80% of 1RM. These exercises were done in addition to the players' normal swimming training sessions. Post-test results showed that there was no change in throwing velocity. What made this programme different from the other studies was that the progressive overload was implemented throughout each training session; i.e., three sets of each exercise were performed during each training session, with the first set requiring a 50-60% intensity, the second set a 70-80% intensity and the third set being at maximum intensity. The other studies (e.g. Gorostiaga et al., 1999; Hermassi et al., 2010; 2011) implemented the progressive overload method throughout the full duration of the training programme. The method used could be the reason why there was no change in throwing velocity after the eight weeks of training.

The results of these studies reviewed suggests that the use of free weights and weighted machines can thus potentially result in an increase in throwing velocity. However, this type of training requires expensive equipment and cannot be incorporated into regular cricket practice sessions.

2.2.3. Specialised fitness machines

Specialised fitness machines are electronic devices used to help one improve the strength or power in a targeted muscle group without the use of weighted resistance. Wooden et al. (1992) designed an individualized, dynamic variable resistance (IDVR) training programme for high school baseball players. When performing resistance training, your muscles are stronger at different points of a repetition but weaker at others. Therefore, IDVR aims to even out that force. For this to take place, a MERAC dynamometer was used. Recreational participants were divided into three groups: an isokinetic group, an IDVR group and a control group. By using the MERAC dynamometer, the IDVR group performed their individualized, dynamic variable resistance training at 100% of the variable resistance training for 6-10 sets of 10 reps, while the isokinetic group exercised at maximum velocity (500°/sec). This was done three times a week for five weeks. The control group did not perform any training throughout this period. The results of this programme showed a significant 3.2km/h increase in throwing velocity for the IDVR group but no change for the isokinetic or control groups. The reason for the increase in the IDVR group but not the isokinetic group can be attributed to each exercise's being personalised to the participant's needs.

Another study that used specialised machines was conducted by Davison et al. (2010). This required one recreational baseball player to train with an inertial exercise trainer (IET). An IET is a low-friction machine that allows players to perform exercise repetitions with high sled accelerations. For 20 weeks, the participant was required to perform 32 different exercises on the IET which targeted the whole body. Additionally, the IET had an added mass of 3.4kg. Post-test results showed that the pitching velocity was improved by 27.3km/h. This is the largest improvement reported among all the studies reviewed, and perhaps can be attributed in large measure to the extended time of the training (i.e. 20 weeks). However, this was a case study of one participant and further research is required to demonstrate the method's effectiveness.

Both the use of IDVR and IET methods would not be ideal for use by amateur club-level cricketers as these machines are generally expensive and not affordable for most amateur clubs. Furthermore, due to time constraints, players would not be able to perform the additional exercises outside of their regular training schedule that this method of training requires.

2.2.4. Combined general resistance training

A combined general resistance training programme has also been shown to have positive effects on throwing velocity. This type of training includes a combination of two or more of the previously mentioned methods of training.

An example of a combination programme is one using both dumbbells and elastic tubing (Escamilla et al., 2012). In this programme, recreational baseball participants performed a six-week Throwers Ten training programme (Escamilla et al., 2012). A Throwers Ten programme is a training programme which consists of 10 basic exercises and is performed by baseball players to increase their arm strength and improve throwing velocity. The programme required the use of dumbbells and elastic tubing for 2 sets of 8-12 reps for each exercise. After six weeks, test results indicated an increase of 1.9km/h for the experimental group. The control group that did not participate in any training showed no change in their throwing velocity. Despite the Throwers Ten programme being a baseball-specific programme, it still did not produce an increase that is comparable to that reported by previous resistance training research, perhaps because the intensity of the exercises did not sufficiently overload the participants.

Similarly, Cricket South Africa has recommended a Super 6 back programme (Cricket South Africa, 2018). Its purpose is to decrease lower back injury and improve bowling velocity. This programme consists of six non-equipment-based exercises which should be performed for 2-3 sets of 30 seconds. It therefore requires a maximum of 9-12 minutes to do, which makes it perfect to include in normal on-field training sessions. However, the effects of this programme on bowling velocity is still unknown as no research has yet reported its findings.

Upon reviewing all the literature above on general resistance training, it seems the most effective method for increasing throwing velocity would be to utilise a moderate to heavy resistance programme consisting of 55-95% of 1RM for the duration of 8-10 weeks. This has the potential to produce a 20km/h increase post training. The problem with this type of training method is that it requires expensive gym equipment, which has cost implications as well as extra training time required outside of normal cricket practice sessions. Of all the exercise routines described above, the only one that could possibly be used during regular training is the Swiss Ball and elastic bands set. However, the gain in velocity using this method was minimal. Table 1, below, offers a summary of all the studies presented in this review making use of general resistance training.

***Table 1**: Summary of the effects of general resistance training on throwing velocity*

Reference	Sport	Number of subjects (and level)	Duration (weeks)	Training method	Significant increase in throwing velocity	Significant change in control group
Bloomfield et al., 1990	Waterpolo	12 (Highly skilled)	8	50-80%; 1RM	No	No
Wooden et al., 1992	Baseball	9 (Recreational)	5	Individual Dynamic Variable Resistance	Yes (3.2km/h)	No
		9 (Recreational)	5	Isokinetic	No	No
Newton and McEvoy, 1994	Baseball	8 (Highly skilled)	8	3 sets; 6-10 reps	Yes (4.7km/h)	No
Gorostiaga et al., 1999	Handball	10 (Skilled)	6	40-90%; 1RM	Yes (2.3km/h)	Decrease
Prokopy et al., 2008	Softball	7 (Skilled)	12	Open kinetic chain	No	No control group
		7(Skilled)	12	Closed kinetic chain	Yes (3.2km/h)	No control group
Davison et al., 2010	Baseball	1 (Recreational)	20	Low friction resistance	Yes (27.3km/h)	No control group
Hermassi et al., 2010	Handball	9 (Highly skilled)	10	Heavy resistance: 80-95%, 1 RM	Yes (22.3km/h)	No
		9 (Highly skilled)	10	Moderate resistance: 55-75%, 1RM	Yes (19.8km/h)	No change
Hermassi et al., 2011	Handball	12 (Highly skilled)	8	80-95%; 1RM	Yes (22.3km/h)	No change
Escamilla et al., 2012	Baseball	14 (Recreational)	6	Throwers Ten	Yes (1.9km/h)	No change
Manchado et al., 2017	Handball	15 (Recreational)	10	Specific and progressive	Yes (3.4km/h)	No change
RM: repetition maximum						

2.3. Special resistance training

Special resistance training is designed to develop one's power through the use of explosive exercises such as ballistic and plyometric exercises (Szymanski et al., 2009). Power is defined as the rate of doing work (Knudson, 2009; Escamilla et al., 2000) and is synonymous with the term 'speed-strength'. Power in the athlete is a variable that strength coaches want to develop to increase velocity. Thus velocity is a component of power and can be defined as the speed in a given direction (Szymanski, 2012). There are various studies that have tried to use special resistance training to improve throwing velocity in baseball (McEvoy & Newton, 1998; Newton & McEvoy, 1994; Escamilla et al., 2012). Each of these studies utilised different training protocols for a different period of time, and their results differ accordingly. The studies that reported a significant increase in throwing velocity made use of plyometric (Escamilla et al., 2012) and ballistic (McEvoy & Newton, 1998) resistance training. One study also made use of pneumatic resistance training (Escamilla et al., 2012).

2.3.1. Plyometric training

Plyometric training are exercises in which muscles exert maximum force for a short period of time in order to improve power. Using this method, Escamilla et al. (2012) required recreational baseball players to follow 32 different exercises as part of a six-week programme. These exercises included two arm throws, chest passes, perpendicular throws, rotary straight arm throws, ear-level throws, hitter push throws, squat jump throws, wood chop slams, diagonal wood chop slams and overhead slams, reverse flies, shoulder extensions, shoulder flexions, scaption with external rotation, trunk rotations, scapular protractions, bench presses, arm accelerations, arm decelerations, and shoulder internal and external rotations with elastic tubing and 1.8-3.6kg medicine balls. To ensure that the exercises done with the elastic tubing were 'plyometric', participants were told to perform them with quick explosive movements. Each exercise was done for one set of 6-10 reps. Post-test results showed an increase in throwing velocity of 2.4km/h, while players in the control group, who did not perform any resistance training, did not improve their throwing velocity.

Another study which utilised plyometric training was that of Newton & McEvoy (1994), whose eight-week programme consisted solely of two-hand chest passes and two-hand overhead throws with a 3kg medicine ball. Highly skilled players were divided into an experimental and control group. The experimental group performed the exercises for three sets of 8-10 reps, whereas the control group only participated in their normal baseball training. Results of this programme showed no significant change in throwing velocity for either group. There are a number of possible reasons why the authors did not achieve significant results after training, including the limited number of exercises (only two were performed), the general nature of the exercises (which was not particularly representative of the baseball throwing action), and the fact that their participants were at an elite level compared to the less skilled participants studied by Escamilla et al. (2012).

2.3.2. Ballistic training

Ballistic training consists of exercises which includes throwing weights and/or jumping with weights in order to improve power. Using a variation of the ballistic training method, McEvoy & Newton (1998) had highly skilled baseball players follow a simple two-exercise programme for 10 weeks while a separate control group only took part in their usual baseball training. The ballistic programme consisted of three sets of 6-8 reps of bench throws and squat jumps on a Plyometric Power System. This device allowed the experimental group to perform these exercises with a load that could be adjusted to maximise the mechanical power output. This led to a 2.2km/h increase in throwing velocity, with no change detected in the control group. This method of training is of course not suitable for performing on the field, with some exercises requiring moreover specialised machines not affordable to amateur cricket clubs.

2.3.3. Pneumatic training

Lastly, Escamilla et al. (2012) implemented a method of variable resistance training called 'Pneumatic resistance training'. This method requires specialised gym equipment known as Keiser Equipment, which uses air as resistance to perform safe, smooth exercises at any speed. The six-week programme had recreational baseball players perform baseball-specific, explosive training for two sets of 8-12 reps for each of the 16 exercises. These exercises were rotational rows, diagonal lifts, diagonal shoulder extensions, diagonal shoulder flexions, arm acceleration, arm deceleration, stability chops, rotatory lifts, flies, reverse flies, and push-pulls. This was done three times a week. The results showed a significant 1.5km/h increase in throwing velocity, but, once again, the Keiser Equipment is specialised machinery that is expensive and cannot be incorporated into regular cricket training.

After reviewing the pertinent literature on special resistance exercises, the most effective method to increase one's throwing velocity is to make use of plyometric training with a 3kg medicine ball for (two handed) throw exercises (2-3 sets of 6-10 reps) for 6-8 weeks, which will result in an approximate 2km/h increase in throwing velocity. Not only does this method improve throwing velocity, it is also quick and easy to perform, inexpensive, and can be done on-field during regular training hours. Table 2 summarises the effects of special resistance training on throwing velocity as reported by these several studies.

__Table 2__: Summary of the effects of special resistance training on throwing velocity

Reference	Sport	Number of subjects (and level)	Duration (weeks)	Training method	Significant increase in throwing velocity	Significant change in control group
Newton and McEvoy, 1994	Baseball	8 (Highly skilled)	8	Plyometric (3 sets; 8-10 reps; 3kg medicine ball)	No	No
McEvoy and Newton, 1998	Baseball	9 (Highly skilled)	10	Ballistic (3 sets; 6-8 reps)	Yes (2.2km/h)	No
Escamilla et al., 2012	Baseball	15 (Recreational)	6	Keiser pneumatic (2 sets; 8-12 reps)	Yes (1.5km/h)	No
		14 (Recreational)	6	Plyometric (1 set; 6-10 reps; 1.8-3.6kg ball)	Yes (2.4km/h)	No

2.4. Specific resistance training

Specific resistance training provides a training stimulus that mimics the body motions and bioenergetic systems that are used in an actual game setting in order to perform a specific activity (Szymanski et al., 2009). The Principle of Specificity states that to become better at a particular skill, one needs to exercise that particular skill regularly (Quinn & Fogoros, 2018). Additionally, the principle predicts that the closer the training routine is to the requirements of the desired outcome, the better the outcome will be. This is due to the vast majority of training-induced adaptations that occur only in those muscle fibres that have been recruited during the exercise regimen, with little to no adaptative changes occurring in the untrained muscles (Hawley, 2008). For hitting or throwing, this can be accomplished by performing batting and bowling training respectively. Furthermore, making use of overweighted and underweighted bats and balls can help to produce further improvement.

2.4.1. Overweight training

Progressive overload, one of the major principles of training, involves continually increasing the stress placed on the body to increase one's force, power or endurance capabilities (Fleck & Kraemer, 2014:10). Presently, the overload principle is used not only in general resistance training but also in different overweighted items of sports equipment such as weighted vests, bats and balls. This overweighted equipment focuses on the overload of force to improve one's strength.

2.4.1.1. Overweighted balls

The same progressive overload principle can be used with overweighted balls. This is a training method that has been used in baseball and handball. These overweighted balls were increased in weight by 5%-25%, 100%, and more than 100%.

2.4.1.1.1. 0%-25% overweight

In both baseball and handball, players utilise a one-hand overarm throw and – as in all sports that require this type of movement – a high ball velocity is important.

DeRenne et al. (1985) implemented a progressive overload programme on recreational baseball players which started out with a standard baseball, then increasing its weight by 5% every two weeks. This programme ran for 10 weeks (until 20% overload). The number of throws done each week was not stated. This resulted in a 2.4km/h increase in throwing velocity. The study was repeated (DeRenne et al., 1990) , with participants performing 150 throws each week. This led to a 6km/h increase in throwing velocity. However, in handball, Edwards Van Muijen et al. (1991) recruited highly skilled national level players to utilise a 25% overweighted ball training for eight weeks at 60 throws per week. There was no significant increase in velocity. The non-significant result in this study could be due to the highly skilled participants recruited or the lower number of throws per week.

The results suggest that overweight balls in the range between 5 and 25% can result in improved throwing velocity. However, the number of balls that are thrown should also be considered.

2.4.1.1.2. 100% overweight

One study utilised a 100% overweighted ball for training. Barata (1992) trained a group of skilled handball players with a 100% overweighted ball for nine weeks. They performed 180-216 throws each week. This resulted in a significant increase of 7% in throwing velocity. The control group also improved their throwing velocity by 6%, despite not doing any extra training.

2.4.1.1.3. More than 100% overweight

Two studies were found that used a ball more than 100% overweight. In the first study, recreational baseball players were divided into two groups: an experimental and a control group (Straub, 1968). The experimental group was required to perform 60 throws a week with a range of 40%-240% overweighted balls. The control group was instructed to perform the same number of throws with a regular weighted ball. This programme lasted for six weeks. The results indicated no increase in either the experimental group or the control group. One can assume that the failure to increase the throwing velocity was a result of the high percentage of overweight that was used in the study, the wide range of difference in modified ball weights, and/or the limited number of throws done per week.

The second study, which used more than 100% overweighted balls, was that of Litwhiler & Hamm (1973). Here, skilled baseballers performed 165 throws each week for 12 weeks, using a range of 40%-140% overweighted balls. This resulted in an 18km/h increase in throwing velocity. The significant increase reported by this study might be due to the smaller weight range of overweighted balls compared to the first study by Straub (1968). Another contributing factor might be the larger number of throws done. However, only 5 participants took part in the study, and without any control group, so care should be taken when results are compared.

Table 3 shows that three out of the four baseball studies reviewed (which made use of overweighted balls) reported an increase in throwing velocity although it is important to note that two of these studies did not have a control group (DeRenne et al., 1985; Litwhiler & Hamm, 1973). A review of the study done by DeRenne et al. (1990) shows that utilising overweighted balls (specifically 10% and 20%) as a method of improving throwing velocity can achieve impressive results. This can be done over a period of 10 weeks. The 100% overweighted ball as used by Barata (1992) in handball could possibly pose a threat of injury if used by recreational cricket players who are not accustomed to performing resistance training with its regular overloads.

Although an average of 115 throws were done per week in the studies reviewed, a similar number cannot be applied to cricket bowling. Cricket Australia developed an age-specific Fast Bowler Workload Recommendation which states that senior fast bowlers (older than 19 years) should be bowling 240-300 balls per week, which includes bowling in matches and practice (Soomro et al., 2018). This was corroborated by Orchard et al. (2015), who showed that fast bowlers who bowled more than 300 balls per week had a higher chance of getting injured one month thereafter.

***Table 3**: The effects of training with overweight balls on throwing velocity and accuracy*

Reference	Sport	Number of subjects	Duration (weeks)	Number of throws per week	Ball weight (% of regular balls)	Significant increase in throwing velocity	Significant change in accuracy	Significant change in control group
Group 1: Throwing with 5-25% overweight balls								
DeRenne et al. 1985	Baseball	5 (recreational)	10	NS	5-20%	Yes (2.4km/h)	NM	No control group
DeRenne et al. 1990	Baseball	10 (recreational)	10	150	5-20%	Yes (6km/h)	NM	Yes (1.4km/h increase)
Edwards van Muijen et al., 1991	Handball	15 (highly skilled)	8	60	25%	No	NM	No
Group 2: Throwing with 100% overweight balls								
Barata, 1992	Handball	11 (skilled)	9	180-216	100%	Yes (7%)	NM	Yes (6% increase)
Group 3: Throwing with more than 100% overweight balls								
Straub, 1968	Baseball	36 (recreational)	6	60	40% – 240%	No	NM	No
Litwhiler & Hamm, 1973	Baseball	5 (skilled)	12	165	40% -140%	Yes (18km/h)	No	No control group
*NS: Not specified; NM: Not measured; N/A: Not applicable								

2.4.2. Underweight training

The progressive overload principle can also be applied to underweighted sports equipment. This method focuses on the overload of speed production that can be achieved by using underweighted balls.

2.4.2.1. Underweighted balls

The use of underweighted balls as a training method has occurred mainly in baseball (DeRenne et al. 1985; 1990; 1993; Fleisig et al., 2006) and in handball (Edwards Van Muijen et al., 1991), where all of the studies found a significant increase in throwing velocity.

DeRenne et al. (1985) was the first to publish the results of using underweighted balls. In this study, recreational baseball players followed an underweighted training programme for 10 weeks (150 throws per week) using 20% underweighted balls. They found that there was a 4.8km/h increase in throwing velocity. This study was repeated in 1990 and 1993. Participants were required to perform 150 throws per week in 1990 and 187 throws per week in 1993. Both these lasted for 10 weeks and reported a 7.6km/h and 3.3% increase in throwing velocity, respectively (DeRenne et al., 1990; 1993). Similarly, in handball, highly skilled female participants were trained for eight weeks performing 60 throws per week using 25% underweighted balls (Edwards Van Muijen et al., 1991). The result was a 1.4km/h increase in throwing velocity. These results suggest that the use of a ball underweighted by about 20-25% can produce an increase in pitching/throwing velocity when used to train participants for 8-10 weeks. However, this does require a large number of pitches (around 150 pitches) for the most effective results (DeRenne et al., 1990; 1993). Care should be taken when extrapolating these study results to cricket bowling.

A summary of the underweighted ball studies is presented in Table 4.

Table 4: *The effects of training with underweight balls on throwing velocity and accuracy*

Reference	Sport	Number of subjects (and level)	Duration (weeks)	Number of throws per week	Ball weight (% of regular balls)	Significant increase in throwing velocity	Significant increase in accuracy	Significant change in control group
DeRenne et al., 1985	Baseball	5 (Recreational)	10	NS	-5 – (-20)%	Yes (4.8km/h)	NM	No control group
DeRenne et al., 1990	Baseball	10 (Recreational)	10	150	-5 – (-20)%	Yes (7.6 km/h)	NM	Yes (1.4km/h increase)
Edwards van Muijen et al., 1991	Handball	15 (Highly skilled)	8	60	-25%	Yes (1.4km/h)	NM	No
DeRenne et al., 1993	Baseball	22 (Recreational)	10	187	-20%	Yes (3.3%)	NM	No
Fleisig et al., 2006	Baseball	34 (Recreational)	N/A	N/A	-20%	Yes (4 km/h)	NM	No control group
*NS: Not specified; NM: Not measured; N/A: Not applicable								

2.4.3. Combined overweight and underweight training

Both overweight and underweight training were found to improve performance by increasing velocity. However, a combination of the two might be even more beneficial. Van den Tillaar (2004) suggests that there are two different views on how to apply a particular type of overload that would be needed to achieve a faster ball movement. Training with overweighted balls is based on the principle of an overload of force whereas training with underweighted balls is based on the principle of an overload of velocity. The theory behind the principles of over- and underweight training can be derived from the force-velocity curve of movement (Figure 1), which is based on the force-velocity curve of muscle contraction as described by Hill (1938).

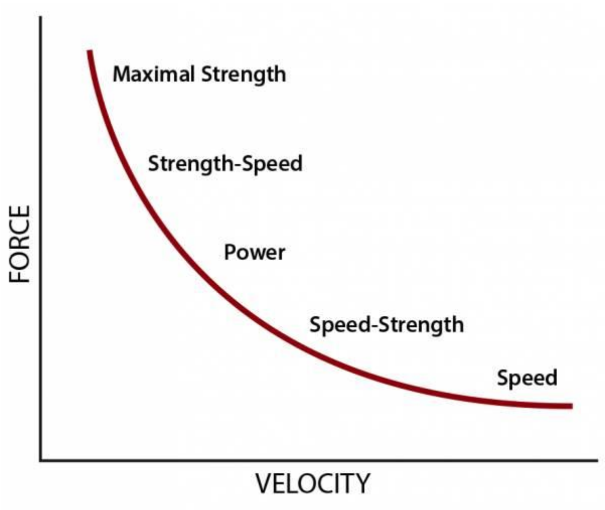

***Figure 1**: Force-velocity curve of movement*

Van den Tillaar (2004) observes that an inverse relationship exists between the force produced and the velocity at which this force is being applied. Therefore, training with heavier loads is said to affect the high force part of the curve whereas training with lighter loads is said to affect the high velocity part of the curve. If training is aimed at increasing velocity, this kind of training should be based on lighter weights and higher velocity. In other words, depending on whether one wants to improve one's strength or speed, according to the force-velocity curve, one would have to train with heavier or lighter loads, respectively, to achieve one's objective. But in order to bowl the 'perfect' delivery, one would need to produce a delivery that hits the 'sweet-spot' of power by incorporating both velocity and force. This reminds us that power is the product of force and velocity (P=F x v). Van den Tillaar & Ettema (2011) note that with underweight implements, you train the arm at faster speeds, whereas with overweight implements, you train the arm with higher loads. These kinds of training programmes have been used successfully in various sports.

2.4.3.1. Overweighted and underweighted balls

Overweight and underweighted ball training procedures have been used successfully to increase ball velocity in baseball (DeRenne et al., 1994; Powe & Deutsch, 2011), handball (Van den Tillar & Marques, 2011a), and cricket (Petersen et al., 2004; Freeston & Rooney, 2008; Wickington & Linthorne, 2017).

Powe & Deutsch (2011) made use of three skilled pitchers to participate in a six-week throwing programme. The throwing programme was a modified overload/underload training programme aimed at increasing the pitching velocity and on-field performance of the athletes. This six-week programme started at the beginning of the season, after the players' current throwing velocities had been measured. Although the weight of the balls used was not mentioned or the exact training programme not stated, Powe & Deutsch found that an interval throwing programme with weighted balls can improve arm strength, increase velocity, increase stamina/endurance and even improve the pitcher's accuracy. DeRenne et al. (1994) found similar results when they utilised a 20% overweighted and underweighted training programme for 10 weeks at 198 throws in training per week. This resulted in a 6.4-8 km/h increase in throwing velocity for the recreational players.

Two cricket studies have tried over- and underweight training on recreational bowlers. First, Petersen et al. (2004) performed a 10-week training programme utilising 3%-16% overweight and underweight balls as well as regular weighted balls (54-108 balls per week) and a control group who only trained with regular balls. The experimental group increased their bowling velocity by 4km/h whereas the control group showed no significant increase in fast bowling velocity. Although there was an increase in velocity for the experimental group, there was also a significant decrease in bowling accuracy. The second cricket bowling study used a combination of underweighted (-10%, -27%, -55%) and overweighted (+27% and +37%) balls for eight weeks of training (Wickington & Linthorne, 2017). After every two weeks of training, the number of deliveries bowled was increased by two balls (36-42 balls per week) while a change in ball weight sequence occurred every training session. This resulted in a 3.5km/h increase in ball velocity for the experimental group. The control group, on the other hand, showed no significant change in ball velocity after training with a standard ball for the same number of deliveries. These results indicate that in cricket relatively few deliveries can be used during training and still produce effective results within 8-10 weeks of training. However, these results were not consistent in handball (Van den Tillaar & Marques, 2011a). Highly skilled handball players were not able to improve their throwing velocity after eight weeks of training (258 throws per week using a 20% heavier and 20% lighter ball). The differences in the results of the handball and cricket studies could be due to the different level of skill of the participants. In the cricket studies recreational bowlers were used whereas in the handball study, highly skilled (national level) players were used. As mentioned previously, the potential for improvement would be greater for the recreational athletes.

Reviewing the literature on combined over- and underweighted implements reveals that the most effective method for increasing throwing velocity appears be training with overweight and underweight balls varying 15-20% from the weight of the regular ball used in that sport. The duration of the training programme can range from 6-10 weeks. Although an average of 228 throws per week was recorded for handball (Van den Tillaar & Marques, 2011a) and baseball (DeRenne et al., 1994), the same number cannot be applied in cricket bowling. This was made clear by Davies et al. (2008), who showed that a bowling workload of that magnitude would result in an increased risk of injury. This is corroborated by Orchard et al. (2015). The Fast Bowler Workload Recommendation (FBWR) developed by Cricket Australia states that no more than 240—300 balls per week should be bowled by senior fast bowlers (older than 19 years). A summary of these studies is presented in Table 5.

***Table 5**: The effects of training with overweight and underweight balls on throwing velocity and accuracy*

Reference	Sport	Number of subjects (and level)	Duration (weeks)	Number of throws per week	Ball weight (% of regular balls)	Significant increase in throwing velocity	Significant increase in accuracy	Significant change in control group
DeRenne et al., 1994	Baseball	150 (recreational)	10	198	±20%	Yes (6.4 – 8km/h)	NM	No
Petersen et al., 2004	Cricket	7 (recreational)	10	54 – 108	±16%	Yes (4km/h)	No, decreased.	No
Powe & Deutsch, 2011	Baseball	3 (skilled)	6	NS	NS	Yes (3-10 km/h)	NM	No
Van den Tillar and Marques, 2011a	Handball	11 (highly skilled)	8	258	±20%	No change	NM	No
Wickington & Linthorne, 2017	Cricket	10 (recreational and skilled)	8	36 – 42	-55%; -27%; -10% +27%; +37%	Yes (3.5km/h)	No change	No
*NS: Not specified; NM: Not measured								

2.5. Combined resistance training

Various studies have tried a combination of two different resistance training types. These include a combination of general and special resistance, special and specific resistance training – specifically, ballistic resistance training and ballistic-specific training as well as a combination of general and specific resistance. One study explored the effects of using all three resistance training types on cricket bowling velocity (Feros et al., 2016).

Ballistic resistance training is a training method which combines elements of plyometric training and weight lifting (McEvoy & Newton, 1998). The "Ballistic Six" programme is a baseball-specific strength training programme and involves six upper extremity plyometric exercises. Each exercise (two types of external shoulder rotations, overhead throws, external rotation side throws, and two types of baseball throws) is performed in three sets of 10-20 reps, using latex tubing and 1kg-4.5kg medicine balls. It has been suggested that baseball pitchers make use of this programme in order to increase shoulder performance and prevent injury (Pretz, 2004). Although the programme is specific to baseball, Singh et al. (2014) introduced the method into an eight-week cricket programme, focusing on improving bowling velocity. Throwing exercises were performed with 1kg and 3kg medicine balls. The results showed a significant but small increase of 2.6km/h in highly skilled cricket bowlers (there was no control group). Although subsequent studies have utilised the "Ballistic Six" programme in ways slightly different from what was recommended by Pretz (2004), the method has been shown to be effective in increasing bowling velocity. Unfortunately, none of these trials included a control group, limiting interpretation of the results.

An alternative combination resistance method is that of ballistic-specific training. This method entails explosive training that is specific to the sport being trained. Van den Tillaar & Marques (2009) used two-arm overhead medicine ball throws in the same manner in which a soccer ball would be thrown. The skilled participants were instructed to perform two explosive sets of eight repetitions of overhead throws with a 5kg (more than 500% overweight) medicine ball over a period of six weeks. A separate control group performed the same workload with a regular soccer ball. There was a significant 2.7km/h increase in throwing velocity for the experimental group, while the control group experienced a much greater increase of 4.3km/h. The relatively small increase in the experimental group could be due to the very large load of the medicine ball. Perhaps a lighter load or a progressive overload would have produced a greater increase in throw velocity. At the same time, the increase in the throwing velocity in the control group could be attributed to the improved biomechanics of throwing with repeated training.

Another successful combination is that of general and specific resistance training (Escamilla et al., 2010). This was done using elastic tubing and distance-based interval throwing long toss program in order to improve baseball throwing velocity in youth baseballers. This combination programme resulted in a significant increase in throwing velocity for the experimental group but no change in velocity for the control group. This programme lasted for four weeks. This is the shortest duration that has found a significant improvement in throwing velocity.

Feros et al. (2016) used a combined general, special and specific resistance training programme to try and improve cricket bowling performance. Recreational cricket bowlers were required to complete an eight-week programme which consisted of pull-ups, sprint training (with and without a weighted vest of 15-20% of bodyweight) and bowling training (overweight and regular ball). The overweighted balls weighed 250g (+60.3%) and 300g (+92.3%). The control group completed unresisted sprint training and regular-ball bowling training. Post-test results showed a 3km/h improvement in bowling velocity for the experimental group, although their bowling accuracy significantly decreased. There was no significant change in bowling velocity in the control group. The increase in bowling velocity notwithstanding, the decline in bowling accuracy could be due to the heavy-ball bowling. Feros et al. (2016) make the point that this alters the sequencing pattern of the bowling motion. This leads to inconsistent delivery release points which in turn results in poorer bowling accuracy. If this is the case, it might be corrected by using a lighter-ball bowling programme alongside the heavy ball. Further, the intensity and frequency of the programme were not stated and therefore could not be assessed.

It seems that all the above-mentioned methods show promising results in increasing ball velocity. Although it appears that the Ballistic Six and a combination of the three resistance training types succeeded in improving ball velocity, it has not been conclusively demonstrated because there was no control group for the Ballistic Six programme (Singh et al., 2014). There is also the decrease in bowling accuracy after application of a combination of the three resistance training types to be reckoned with (Feros et al., 2016). One would need to implement practical changes to these studies in order to make sure of an improvement in bowling velocity. Table 6 presents a summary of the above studies.

Table 6: *Summary of combined resistance training on throwing velocity*

Reference	Sport	Number of subjects (and level)	Duration (weeks)	Training method	Significant increase in throwing velocity	Significant increase in accuracy	Significant change in control group
Van den Tillaar & Marques, 2009	Soccer	32 (skilled)	6	Ballistic specific	Yes (2.7km/h)	NM	Yes (4.3km/h increase)
Singh et al., 2014	Cricket	27 (highly skilled)	8	Ballistic Six (3 sets; 10-20 reps; 1kg and 3kg medicine ball)	Yes (2.6 km/h)	NM	No control group
Feros et al., 2016	Cricket	12 (recreational)	8	General, special, specific resistance	Yes (3.3km/h)	No, decreased.	No
Escamilla et al., 2010	Baseball	17 (recreational)	4	General and specific resistance	Yes (3.6km/h)	NM	No
*NS = Not specified; NM = Not measured; N/A = Not applicable							

2.6. Upper body power

Upper body power can be measured in various ways. These include variations of the seated medicine ball toss (Clemons et al., 2010; Nash, 2008), an overhead medicine ball throw, a sidearm medicine ball throw, a force-velocity power test (Hermassi et al., 2010; 2011), and an upper body wingate anaerobic test.

The seated medicine ball toss test can involve a seated medicine ball toss on a 45° incline bench, or being seated on the floor with one's back against a wall. The 45° incline helps to facilitate the 45° angle and to produce an arm-to-torso angle similar to that. The other variation requires the participant to sit with their back against a wall and their legs stretched out flat in front of them. To facilitate the 45° angle for throwing, two horizontal bars are placed for the medicine ball to be thrown through.

Although both tests are acceptable methods of measuring upper body power, the equipment needed does not allow for them to be performed on-field, and therefore a variation of the method with limited equipment would be more appropriate. This was done by Johnson & Nelson (1979), who used a chair for participants to sit on when tossing the ball.

Upper body power was not measured in any of the previous studies reviewed, whether in general, special or specific training.

2.7. Lower body power

It has been found that lower body power can be measured using a squat jump test, a standing long jump test, a countermovement jump test, and a force-velocity power test.

The squat jump test requires players to begin in a squat position and perform a vertical explosive jump. This must be done without the assistance of the arms (which must be held against chest) (Samozino et al., 2008; Gorostiaga et al., 1999). The standing long jump test requires players to perform a long jump from a standing position. Players are permitted to begin the jump with bent knees and swing their arms to assist in the jump. This long jump test has also been modified in a number of different ways to obtain similar results (Almuzaini & Fleck, 2008).

The countermovement jump test (Hermassi et al., 2011) begins in an upright position, making a fast downward movement to a knee-angle of 90° then forcefully pushing off the ground, going upward.

Both the squat jump and the countermovement jump test were used by Gorostiaga et al. (1999) and Hermassi et al. (2011) to measure their participants' leg power. Despite a significant increase in throwing velocity in both studies, there was no significant change measured in the countermovement jump test. The squat jump test showed no significant increase for Gorostiaga et al. (1999), but a significant increase for Hermassi et al. (2011).

Despite the lack of improvement post training in these studies, the countermovement jump test as a method of measuring lower body power remains a reliable and valid one (Markovic et al., 2004). The countermovement jump test has also been shown to have an advantage over the squat jump (Linthorne, 2000), and therefore seems an appropriate test with which to measure lower body power.

2.8. Accuracy

In cricket fast bowling, accuracy can be just as important as ball velocity (Woolmer et al., 2008). Accuracy should therefore be included as an indicator when measuring fast bowling performance (Portus et al., 2000). Utilising a weighted-implement training programme could compromise a fast bowler's accuracy (Wickington & Linthorne, 2017). There have been several studies measuring bowling accuracy (Portus et al., 2000; Taliep et al., 2003; Petersen et al., 2004; Freeston et al., 2007; Phillips et al., 2012; Feros et al., 2013; 2016; Murtaza et al., 2014). Some studies used an upright target area (Portus et al., 2000; Freeson et al., 2007; Phillips et al., 2012; Feros et al., 2013; 2016), while others used a target area on the pitch (Taliep et al., 2003; Petersen et al., 2004; Murtaza et al., 2014).

2.8.1. Upright target zone

Phillips et al. (2012) designed what is probably the most practical and effective measure of accuracy for fast bowlers. A target area (200cm x 120cm) comprising 20cm x 20cm squares was placed vertically upright at the position of the stumps. Points were awarded according to where the target was hit, with 100 points for a good delivery hitting the equivalent of the top of off-stump. Points for the different squares ranged from 0 to 100, depending on how far the square was from the core area of the target.

Portus et al. (2000) made use of a 140cm x 100cm target grid which consisted of three scoring zones (100, 50 & 25 points). This grid was suspended 30cm in front of the batter's stumps and 50cm above the ground. The design of the grid allowed for a maximum score of 100 points for all deliveries bowled passing a line of middle stump to approximately 25cm outside off stump and all deliveries bowled from a good length or just short of a good length. Similarly, Freeston et al. (2007) used five marked scoring zones that were specifically designed to surround one cricket stump in the ground. Accuracy was measured according to the following schema: direct hit on the stump = 0 points, zone one = 1 point, zone two = 2 points, zone three = 3 points, zone four = 4 points and the outer zone = 5 points. A perfect score equated to 0 points. Feros et al. (2013; 2016) used a vertical, five-point target system. The distance between the impact of the delivery and the target was digitised and used as a measure of accuracy.

Although all these grid systems are similar, the method used by Phillips et al. (2012) has an advantage over the other grid systems because it can be adjusted for changes in length of the deliveries and has more target scoring zones to accommodate this.

2.8.2. Target zone on a pitch

Other researchers used targets placed on the pitch (Taliep et al., 2003; Petersen et al., 2004; Murtaza et al., 2014). An area was marked out for the duration of the trial, and the targets that were placed in various positions on the pitch measured a certain line and length of delivery. The disadvantage of this technique is that it measures accuracy prior to the ball reaching the batter and wicket. Bowlers have different statures and swing the ball differently, and therefore the ball will deviate differently off the pitch. A ball can bounce on the perfect target zone on the pitch but because of the swing end up deviating far off the ideal position when it passes the batter. The advantage of placing the target upright in either the position of the stumps or the position of the batter is that it represents where the ball is as it passes the wickets/batter.

2.9. Exercise adherence

Adherence is defined as the degree to which participant behaviours coincide with the recommendations of the provider or trainer (Rand & Weeks, 1998), or the level of participation achieved in a behavioural regimen once the individual has agreed to undertake it (King, 1994). A broader definition of adherence has it meaning sticking to or faithfully conforming to a standard of behaviour in order to meet a particular goal (Haynes, 2001).

There are many reasons why participants do not adhere to exercise programmes. These include injury, the exercise being too strenuous, failure to meet goals, travel (personal or job related), lack of interest, lack of time, lack of instruction, family demands, and physical and mental fatigue (Anshel & Seipel, 2009). Strategies that help to prevent non-adherence and improve participant compliance with exercise programmes are referred to as relapse prevention (Marlatt & George, 1998). Marcus et al. (2000) suggest that in order to reduce relapse, participants should develop feelings of self-control. Non-adherence to protocol can be prevented through self-monitoring, using daily logs and diaries, or through self-report questionnaires.

Self-monitoring and instructor monitoring have been found to increase participant adherence significantly (Weber & Wertheim, 1989; Bassett, 2003; Cadmus-Bertram et al., 2014). Weber & Wertheim (1989) tested the self-monitoring method to determine whether it would be successful in increasing exercise adherence. One group of participants was required to perform self-monitoring; a second group was required to do this while at the same time receiving reinforcement and attention from staff involved in the study; and a third group was used as a control. The two experimental groups were given a self-monitoring sheet to complete each time they visited the gym. The results of this study indicate that exercise adherence was significantly poorer in the control group compared to the self-monitoring groups, while the solely self-monitoring group recorded a degree of adherence superior to the other groups.

Bassett (2003) investigated measures of adherence to in-clinic and home-based physiotherapy programmes. Clinic-based adherence comprised the patient's clinic attendances whereas home-based adherence consisted of patient diaries and self-report questionnaires. Patients were expected to complete their diaries each time they performed their home programme and take them to each clinic appointment. An advantage of the diary is that it can serve as a reminder to the participant to do what the programme requires of them, but it could also become a limitation due to patient's simply forgetting to write in it. Clinic attendance can also be inconclusive because it does not measure the patient's adherence during clinic visits. Similarly, exercise logs have been used to monitor adherence in athletes (Cadmus-Bertram et al., 2014). Although all these studies utilise the self-monitoring method, they have certain limitations. Some athletes lie about their performance of the training programme – for instance, they could log/diarise a session without actually doing it – or are simply unable accurately to recall their adherence (Myers & Midence, 1998).

An alternative method to ensure that participants are performing what is required of them is to have training personnel present at training sessions. This enables the training personnel to observe participant adherence to the protocol and then rate this adherence on a scale of none (0) to all (5) (Taylor & May, 1996). Not only does this ensure that athletes are performing the training programme, it also checks that they are performing it correctly, i.e. using the correct techniques. However, this is not always practical when there are numerous participants in different locations training at the same time.

2.10. Summary

The primary aim of this section has been to review the relevant literature on resistance training to improve ball velocity in various ball sports, and then make recommendations on a possible training programme suitable for recreational cricket fast bowlers. The following factors were considered: type of resistance training, duration, sets and repetitions, the intensity and time per session, the availability of equipment, and the measures of upper and lower body power.

2.10.1. Type of training

It seems that the use of a combined resistance training programme which consists of general, special and specific resistance exercises could potentially produce the best results. In developing the programme, it must be decided which methods of training would be most effective and efficient. General resistance training should be done through various bodyweight exercises. For special resistance, plyometric training (with a 3kg medicine ball) would be ideal. For specific resistance, training with heavier, lighter and regular balls would be effective in helping to improve bowling velocity. These balls should weigh approximately 15-20% more/less than the regular ball. The weight range will depend on the duration of the programme being implemented. However, a conservative approach would be to slowly overload the system by using a slightly lower weighted implement (starting at 10%) to decrease the risk of injury.

2.10.2. Duration

According to the literature reviewed, the recommended duration of a programme is 6-10 weeks. However, if a combination of general, special and specific training is implemented then perhaps a shorter duration (four weeks) could be used (Escamilla et al., 2010). Additionally, this shorter duration can be done for amateur recreational players as they may have a greater capacity for change compared to elite players. Furthermore, the literature suggests that the longer the protocol, the lower the adherence (Bassett, 2003). The four-week programme would be ideal for recreational club cricketers to use to improve bowling performance within a short period of time.

2.10.3. Sets and repetitions

The programme should provide a progressive overload of sets and repetitions from the first week of training until completion of the programme. For both general and special resistance exercises, a minimum of two sets and six repetitions should be effective to kick-start the programme. Thereafter, a progressive overload should take place every two weeks. With regard to the specific resistance, the weight of the balls can be increased/decreased by 5% every two weeks to provide for enough overload to provoke an adequate response. Additionally, the number of deliveries bowled during training should be increased by one over (six deliveries).

2.10.4. Intensity

The studies reviewed states that all special resistance training was performed at maximal explosive effort. Therefore, when performing the suggested protocol, one should perform all power exercises with maximum exertion. This can also be applied to the weighted ball protocol.

2.10.5. Time per session

The studies reviewed did not mention the time it took to complete a resistance training session. However, based on the studies we estimated the time could vary between 20 minutes and one and a half hours. Ideally, we require a programme that can be performed during regular cricket training and the exercises require minimal time and resources to perform. Bowling with overweighted balls can occur during regular training in the nets and would not add to the allocated time. The only extra time would be allocated to the general and special resistance training which will add an approximately 20 minutes to their training sessions.

2.10.6. Cost of and access to equipment

Based on previous literature, various equipment was utilised to perform the different training protocols, however, most of these were quite expensive and inaccessible during regular training. Mobile and cost-effective equipment is necessary for on-field training session of amateur cricket bowlers. This can be in the form of a 3kg medicine ball and weight-modified cricket balls.

2.10.7. Measures of upper and lower body power

To measure upper body power, previous research shows that there are various methods to do so, however, the seated medicine ball throw test (on a chair with a 3kg medicine ball) seems to be the most effective as it is simple and safe to administer. This requires limited equipment compared to other variations of this same test. Similarly, previous research shows various methods to measure lower body power. However, the countermovement jump test has shown to have an advantage over similar tests. Both these tests are reliable and valid. These recommendations can be implemented in a combined resistance training programme.

2.11. Hypothesis

Based on the literature review the following hypotheses were formulated:

2.11.1. After two weeks

Hypothesis 1:

There will be a significant increase in bowling velocity after two weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ vb > μ va
Where:
vb = velocity after two weeks,
va = velocity at baseline

Null-hypothesis 1:

The null-hypothesis is that there will be no significant change in bowling velocity after two weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ vb = μ va
Where:
vb = velocity after two weeks,
va = velocity at baseline

Hypothesis 2:

There will be no change in bowling accuracy after two weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ ab = μ aa
Where:
ab = accuracy after two weeks,
aa = accuracy at baseline

Null-hypothesis 2:

The null-hypothesis is that there will be a significant decrease in bowling accuracy after two weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ ab < μ aa
Where:
ab = accuracy after two weeks,
aa = accuracy at baseline

Hypothesis 3:

There will be a significant increase in upper body muscle power after two weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ ubpb > μ ubpa
Where:
ubpb = upper body power after two weeks,
ubpa = upper body power at baseline

Null-hypothesis 3:

The null-hypothesis is that there will be no significant change in upper body muscle power after two weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ ubpb = μ ubpa
Where:
ubpb = upper body power after two weeks,
ubpa = upper body power at baseline

Hypothesis 4:

There will be a significant increase in lower body muscle power after two weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ lbpb > μ lbpa
Where:
lbpb = lower body power after two weeks,
lbpa = lower body power at baseline

Null-hypothesis 4:

The null-hypothesis is that there will be no significant change in lower body muscle power after two weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ lbpb = μ lbpa
Where:
lbp = lower body power after two weeks,
lbp = lower body power at baseline

2.11.2. After four weeks-

Hypothesis 1:

There will be a significant increase in bowling velocity after four weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ vb > μ va
Where:
vb = velocity after four weeks,

va = velocity at baseline

Null-hypothesis 1:

The null-hypothesis is that there will be no significant change in bowling velocity after four weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ vb = μ va
Where:
vb = velocity after four weeks,
va = velocity at baseline

Hypothesis 2:

There will be no change in bowling accuracy after four weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ ab = μ aa
Where:
ab = accuracy after four weeks,
aa = accuracy at baseline

Null-hypothesis 2:

The null-hypothesis is that there will be a significant decrease in bowling accuracy after four weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ ab < μ aa
Where:
ab = accuracy after four weeks,
aa = accuracy at baseline

Hypothesis 3:

There will be a significant increase in upper body muscle power after four weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ ubpb > μ ubpa
Where:
ubpb = upper body power after four weeks,
ubpa = upper body power at baseline

Null-hypothesis 3:

The null-hypothesis is that there will be no significant change in upper body muscle power after four weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ ubpb = μ ubpa
Where:

ubpb = upper body power after four weeks,
ubpa = upper body power at baseline

Hypothesis 4:

There will be a significant increase in lower body muscle power after four weeks of resistance training.

Stated statistically the alternate hypothesis is:

H_1: μ lbpb > μ lbpa
Where:
lbpb = lower body power after four weeks,
lbpa = lower body power at baseline

Null-hypothesis 4:

The null-hypothesis is that there will be no significant change in lower body muscle power after four weeks of resistance training.

Stated statistically the null-hypothesis is:

H_0: μ lbpb = μ lbpa
Where:
lbp = lower body power after four weeks,
lbp = lower body power at baseline

CHAPTER THREE

METHODOLOGY

This chapter describes the design of the study and the questionnaire that was administered to the participants during the cricket season. It then outlines the testing procedures and the training programme that was implemented.

3.1 Study design and ethical considerations

A cross-sectional, randomised control study design was employed for this study. This study conforms to the principles and tenets of the Helsinki Accord and was approved by the Research Ethics Committee of Cape Peninsula University of Technology (2016FBREC359). No participant entered the study without signing an informed consent form after the researcher had provided a full oral and written explanation of the study, including the possible risks involved.

3.2 Questionnaire

Before the commencement of the study, a questionnaire for fast bowlers to complete was sent out to various cricket clubs (1st and 2nd division) in the Western Province region, as well as distributed online. This questionnaire was based on their cricket training and strength training load. The questionnaire retrieved demographic and injury information as well as perceptions of the importance of strength and power training. Participants were asked to state whether they had personally implemented training that contributed to an improvement in their bowling velocity and if they had a gym membership. Additionally, participants were asked their experience (in years) in bowling as well resistance training (Feros et al., 2019). This questionnaire was answered by 49 players and was used to determine whether players at club level had the time and financial resources to perform additional strength or power training (outside of their normal cricket training hours) that might produce an improvement in their bowling performance. The questionnaire that was given to the participants is presented in Appendix B.

3.3. Experimental trial

3.3.1 Participants

Male, first-division recreational club cricketers in the Western Cape, South Africa (n = 20), between the ages of 18 and 35, were recruited for the research study. All the participants had been injury-free for at least one month prior to commencement of the trial. The participants were divided into experimental (n = 11) and control (n = 9) groups according to their respective clubs. The experimental group trained with a combination of overweighted, underweighted and regularly weighted cricket balls and followed a simple strength and power training programme, twice a week for a period of four weeks. The experimental group was instructed to complete the prescribed training programme and not perform any other, additional resistance training. Once the bowlers completed their resistance training programme, they were allowed to continue their regular bowling training by bowling extra deliveries if required with regular weighted balls only. This could minimise interference with their regular club training sessions. No record was kept of the total volume of balls bowled per week with the regular weighted balls. Of the experimental group, nine participants completed the study trial because one participant dropped out (due to lack of interest), while another sustained an injury after two weeks. The control group only trained with regulation weight balls, twice a week throughout the four-week trial period and were instructed not to take part in any resistance training. The control group's practice sessions consisted of various cricket activities (bowling and fielding), provided that their bowling sessions were done with a regular weighted (156g) cricket ball. No record was kept of the total volume of balls bowled per week with the regular weighted balls. All nine participants in the control group completed the study trial. The control group not informed of the purpose of the study and no mention of the use of differently weighted cricket balls was made (Appendix A). Further, because participants were divided according to their club, no club had players belonging to both groups. This was done to minimise the players' awareness of the purpose of the study, as this could influence the way they responded to the testing. After the completion of the study, the control group was provided with the training programme for personal use.

3.3.2. Testing facility

Testing took place at an indoor sports facility at the Sports Science Institute of South Africa. The facility has a full-length cricket pitch as well as enough space for participants to make use of their full run-up (Figure 2).

3.3.3. Anthropometric measures

Mass and stature (without shoes) were measured prior to the commencement of the trial. These were collected for potential data analysis purposes.

3.3.4. Testing Procedure

Prior to the commencement of the experimental and control trials, all the participants performed a baseline test (pre-test). Thereafter, participants were tested after the second week of training and after the fourth week of training. Before each test session, participants were required to complete their usual warm-up routine, followed by a specific warm-up of several deliveries beginning with light-intensity bowling, progressing on to high-intensity bowling at the completion of the warm-up. The testing only started once the players were satisfied that they had warmed up sufficiently. All test data was recorded on individual data sheets (Appendix B).

***Figure 2**: Full length cricket pitch and placement of radar gun and high speed camera*

3.3.4.1. Bowling velocity

Participants were instructed to bowl six good-length deliveries (4-7 metres from the batting crease) at their fastest speed while trying to hit the top of off-stump after the bounce (left hand stump as seen by the bowler when approaching the stumps). The velocity of each delivery was measured using a radar gun (Stalker Pro II; USA) on transmission mode, which was placed on a tripod at the end of the participant's run-up, directly behind the position where he released the ball. The mean bowling velocity of the six deliveries was recorded.

3.3.4.2. Accuracy

Bowling accuracy was also measured in this trial, to determine whether the predicted change in ball velocity had an influence on the delivery's accuracy. The same upright target grid as used by Phillips et al. (2012) was applied to measure the bowling accuracy. This grid replicated the accuracy scoring system for good length deliveries (**Error! Reference source not found.**). It contains several 20cm x 20cm squares with different point values. The mean of the total points accumulated during the bowling over was used for data analysis. The location of where the ball made contact with the target grid was recorded with a Casio Exilim EX-FH20 high speed video camera (recorded at 210Hz), which was placed on a tripod at the end of the participant's run-up, directly behind the position where the participant released the ball (Figure 2). This was used to analyse their accuracy after the test session was completed. The mean bowling accuracy of the six deliveries was used in the analysis.

0	0	0	0	0	
0	25	50	25	0	
0	75	90	50	0	
25	90	**100**	75	0	
0	75	90	50	0	
0	25	50	25	0	
0	0	0	0	0	

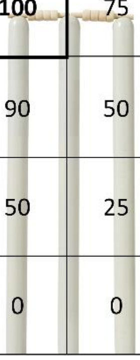

***Figure 3**: Target grid used to measure bowling accuracy (taken from Phillips et al., 2012)*

3.3.4.3. Upper body power

Upper body power was measured by making use of a seated medicine ball throw test (Jones et al., 2016). This test was found to be both valid and reliable measure of upper body power. Seated participants were instructed to hold the medicine ball with both hands behind the ball at chest level. From the chest, the medicine ball was pushed up and outward at approximately a 45° angle as forcefully as possible (Figure 4). Participants were allowed three warm-up throws before performing the test. The distance was measured in centimetres from the front legs of the chair to where the ball landed. The furthest distance of three attempts was reported.

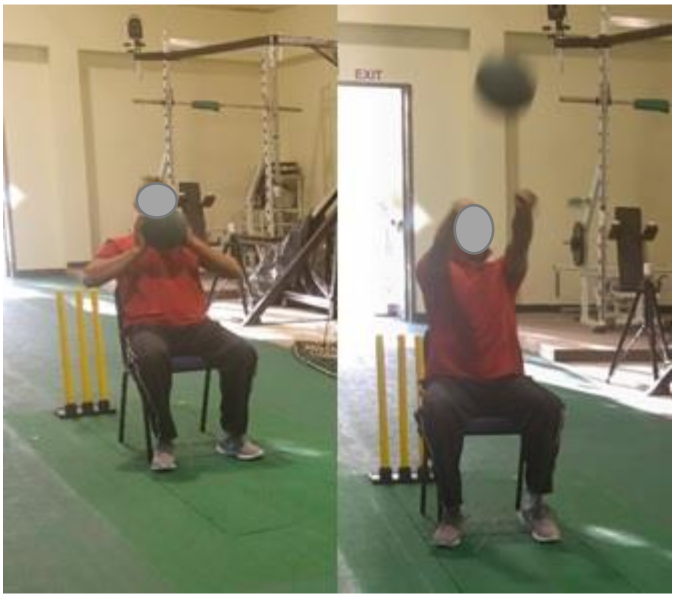

Figure 4*: Seated medicine ball throwing test*

3.3.4.4. Lower body power

To measure the participant's lower body power, a countermovement jump test (Figure 5) was conducted by using the Vertec (Jump USA; California). The countermovement jump is a valid and reliable measure of lower body power (Markovic et al., 2004). The Vertec is an instrument commonly used to measure one's vertical jumping ability. Participants were instructed to keep their feet flat on the ground and reach up with the hand closest to the Vertec. The standing reach height was measured where the highest vane was reached. Thereafter the jump height was measured. This was performed by the participant leaping vertically as high as possible using a countermovement. The jump height was measured as the highest vane reached. The difference between the standing reach height and the jump height is the score recorded. Participants were allowed three warm-up tries before performing an additional three jumps. The highest jump of the three jumps was used for analysis. All measurements were taken in metres.

Figure 5: *Countermovement jump test*

3.3.5. Training protocol

3.3.5.1. Experimental group

Ball modification

Four-piece regulation, regularly weighted (156g) cricket balls were manufactured for use in this study trial. Non-regulation (overweight and underweight) balls were manufactured by either increasing or decreasing the weight of the cork in the ball. All balls were manufactured by the same manufacturer.

Weighted implement training (use of over- and underweight balls)

The sport-specific bowling protocol utilised overweighted, underweighted and regularly weighted cricket balls during training. Participants were required to deliver 24 balls in the first two weeks (8 balls regular weight [156g ball], 8 balls at 10% overweight [172g ball] and 8 balls at 10% underweight [141g ball]). In the next two weeks, 30 balls were delivered per session (10 balls regular weight [156g], 10 balls at 15% overweight [179g] and 10 balls at 15% underweight [133g]). During each week, the participants were required to complete two training sessions. A summary of the overweighted and underweighted values for each training session is presented in Table 7 .

Table 7*: Weighted implement training schedule for the experimental group*

TRAINING WEEKS	BALL SEQUENCE AND WEIGHT (g)	BALL WEIGHT (%)	BALLS BOWLED PER SESSION

1-2	4x (156) 8x (172) 8x (140) 4x (156)	4x (0%) 8x (10%) 8x (-10%) 4x (0%)	24 (4 overs)
3-4	5x (156) 10x (179) 10x (133) 5x (156)	5x (0%) 10x (15%) 10x (-15%) 5x (0%)	30 (5 overs)

*Overweight and underweight balls were rounded off to the nearest gram.

Power and Strength Training programme

All participants were familiarised with the strength training programme prior to commencement of the trial. This was done after the baseline testing. The strength and power training programme used by the experimental group was as follows (Table 8):

Table 8: *Summary of 4-week training programme.*

Week	Exercise name	Type of resistance training	Sets	Repetitions
1-2	Bodyweight squats	General	2	10
	Bodyweight split squats	General	2	6
	Bilateral hip raise	General	2	10
	Chest pass	Special	2	6
	Recoiled overhead slams	Special	2	6
	Standing side toss	Special	2	6
	Recoiled rotational throws	Special	2	6
3-4	Bodyweight squats	General	2	12
	Bodyweight split squats	General	2	8
	Bilateral hip raise	General	2	12
	Chest pass	Special	2	8
	Recoiled overhead slams	Special	2	8
	Hop back and throw	Special	2	8
	Step behind and throw	Special	2	8

3.3.5.2. Control group

Participants in the control group were required to perform their normal training protocol during each session, only bowling with a normally weighted ball. They were requested not to participate in any resistance training during the 4-week trial period.

3.3.6. Exercise adherence

To determine whether participants in the experimental group adhered to the training protocol as required, an attendance adherence survey was conducted. Furthermore, to increase exercise adherence, the investigator randomly visited the training sessions of the participants to monitor and assist them if required. The coaches at the clubs were also familiarised with the exercises and the training protocol to further assist the players and increase adherence to the trial.

3.4. Data analysis and statistics

For the questionnaire, simple percentages were reported. Statistical power for bowling velocity was conducted through a general linear model, repeated-measures analysis of variance, within- between factors (the F test). A minimum of 18 participants were required for this study (9 per group). The alpha error probability was set to 0.05 and the power (1-β error probability) was 0.96, for the 2 groups with 3 repeated measurements (baseline, 2-weeks and four weeks). All data were first checked for normality (the Shapiro-Wilk test), kurtosis, and skewness with respect to each group. All variables were approximately normally distributed. Mean (± SD) of the descriptive data, fitness characteristics and bowling performance were calculated. For the experimental trial, the measurements of the experimental and control groups were compared using a General Linear Model, repeated measures (within-subjects) were performed and the confidence interval were adjusted using Bonferroni correction. Statistical significance was considered when $p < 0.05$. Effect sizes were reported by the Hedge's g statistic. The precision of mean differences was expressed with 95% confidence limits (95% CLs). Qualitative descriptors of standardised effect sizes using Hedge's g were assessed using the criteria: trivial, less than 0.2, small 0.2–0.49, moderate 0.5–0.79, and large 0.8. For this analysis, both the experimental and control group data were pooled to achieve within subject comparison. All statistical analyses and calculations were performed using IBM SPSS Statistics (25 IMB Corp., Armonk, NY, USA) or Microsoft Excel (version 2013; Microsoft Corp.).

CHAPTER FOUR

RESULTS

This chapter presents the results obtained from the questionnaire and the experimental trial. The results of the exercise adherence survey are also reported.

4.1 Questionnaire

A total of 49 participants completed the questionnaire.

4.1.1 Employment and student status

Employment status	Full time	Part- time	Unemployed
	52%	17%	31%

Scholar status	Full time	Part- time	Not studying
	38%	6%	56%

Participants were required to state whether they were employed/unemployed and/or if they were a full-time or part-time student. Fifty-two percent of participants were employed full time, 17% were part-time employees and 31% were unemployed. Thirty-eight percent of participants were full-time students, 6% were part-time students and 56% were not students.

4.1.2 Injury

At the time of the questionnaire being completed, 9 participants reported having sustained an injury. These included various back injuries, ankle and heel, shoulder, and groin injuries. These participants were excluded from the experimental study.

4.1.3 Club cricket playing time

Cricket playing time	Years of playing	Hours per week
	10.5	9 ± 4.9

Participants were asked to state how many years they had been playing club-level cricket. The average time of this was 10.5 years. Participants were also asked how many hours and days per week they spent on club-level cricket. This amounted to a mean of 9 hours per week (±4.9 hours) which included match days.

4.1.4. Strength training

	Yes	No
Strength training in season	56%	44%
Gym contract	43%	57%

Participants were asked if they took part in strength training during the cricket season, if they had a gym contract, and if they utilised it. Fifty-six percent of participants claimed they performed strength training during the cricket season, while 44% did not. Forty-three percent of participants confirmed that they had a gym membership, while only 24% of those actually go to gym for strength training. The participants who did not have a gym membership (57%) were required to state why. The main reasons given were that it was too expensive or that they did not have the time to attend. Some of them nevertheless tried to perform some sort of strength and power training at home. The additional training time amounts to a mean of 4 hours per week.

4.1.5. Increasing bowling velocity

Participants were also asked to rate, on a Likert scale of 1-5, how important they thought strength and power training was for cricket bowling. A total of 88% of participants rated it as either 'very important' or 'important'. Despite this, only 38% of them had previously undergone training to increase their bowling speed. The types of training done included weight lifting, working on leg, shoulder, back or core strength, and working on their run-up, technique or hand speed.

4.2. Experimental trial

4.2.1. Participant characteristics

The age, stature and mass of the participants are reported in Table 9. Of the 11 participants in the experimental group, one participant dropped out because of an injury sustained unrelated to cricket while another dropped out due to lack of interest.

***Table 9**: Participant characteristics*

	Experimental group (*n* = 9)	**Control group (*n* = 9)**	***p* – value**
Age (years)	22.2 ± 5.4	28.3 ± 7.7	0.069
Height (m)	1.78 ± 0.1	1.72 ± 0.1	0.231
Mass (kg)	73.0 ± 8.3	77.0 ± 21.4	0.605
Resistance training experience (years)	0.9 ± 1.1	3.3 ± 4.6	0.116
Pace bowling experience (years)	10.3 ± 5.5	12.0 ± 5.2	0.518

4.2.2. Velocity

A repeated measures ANOVA showed that mean velocity differed significantly after four weeks of training [$F(2, 7) = 51.5$, $p < 0.001$]. Post hoc, Bonferroni correction, revealed that the velocity increased by an average of 4.2 km·h-¹, 95% [1.6, 6.7], effect size: $g = 0.52$, $p = 0.003$ after 2 weeks and a total increase of 5.1 km·h-¹, 95% [3.7, 6.6], effect size: $g = 0.65$, $p < 0.001$) after four weeks of training (Figure 1). It is noteworthy that there was non-significant difference in velocity between two-weeks and four weeks of training [0.97 km·h-¹, 95% (-1.4, 3.3, effect size: $g = 0.12$, $p = 0.756$)] (**Figure 6**). In the control group, there were no significant differences in the bowling velocity across the trial [$F(2, 7) = 0.42$, $p = 0.674$] (**Figure 6**).

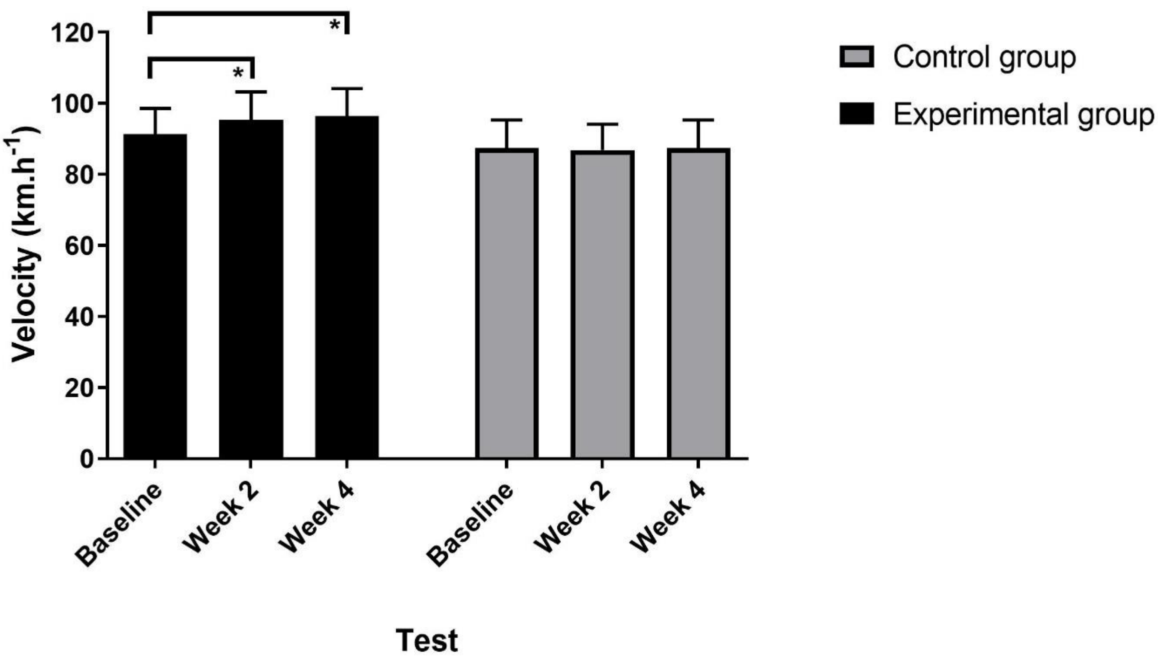

***Figure 6**: Change in mean velocity for the experimental and control group across the 4-week training period. * represents significant differences, p< 0.05*

4.2.3. Accuracy

There was no significant difference between accuracy across the four weeks for both the experimental [F (2, 7) = 0.72, p = 0.520] and control group [F (2, 7) = 0.35, p = 0.718] (Figure 7).

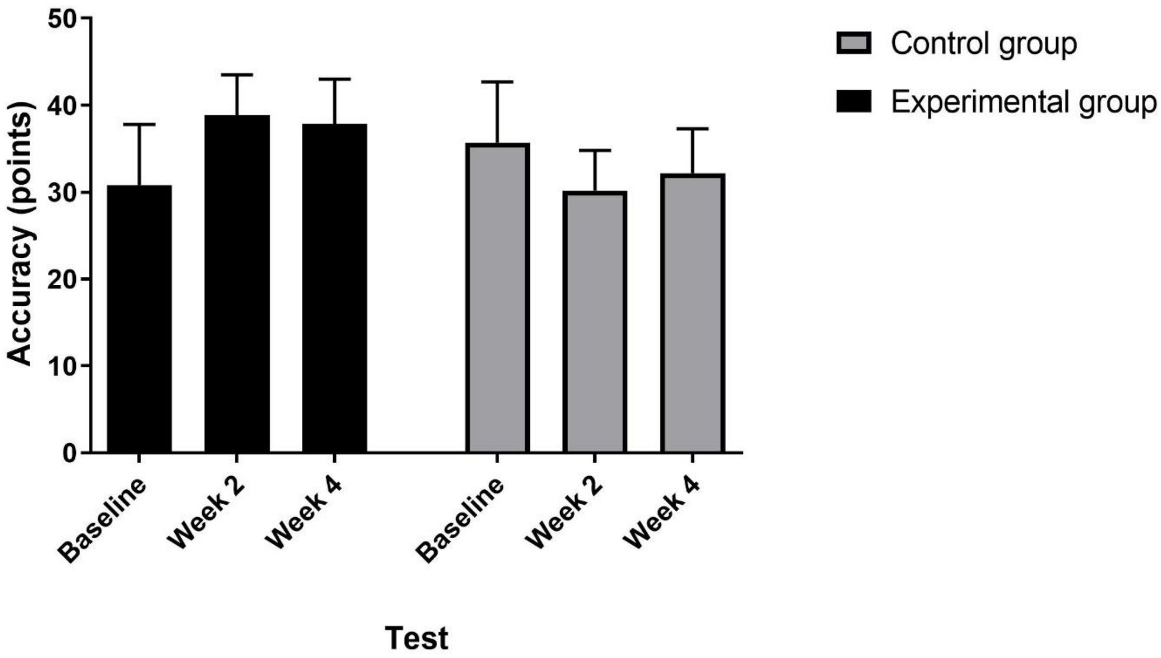

Figure 7: *Change in mean accuracy for the experimental and control group across the 4-week training period.*

4.2.4. Upper body muscle power

There was non-significant increase in the throw distance across the four weeks [F (2, 7) = 2.2, p = 0.179] in the experimental group. However, there was a moderate effect size between baseline and week two (g = 0.65) and a near medium effect size between baseline and four weeks of training (g = 0.45). The control group showed a significant difference in the throw distance across the four weeks ([F (2, 7) = 7.6, p = 0.018]. The mean throw distance significantly increased between the baseline test and 2 weeks (0.24 m, 95% [0.02, 0.46], effect size: g = 0.319, p = 0.032) and between baseline and four weeks (0.33 m, 95% [0.08, 0.59], effect size: g = 0.397, p = 0.013) (Figure 8).

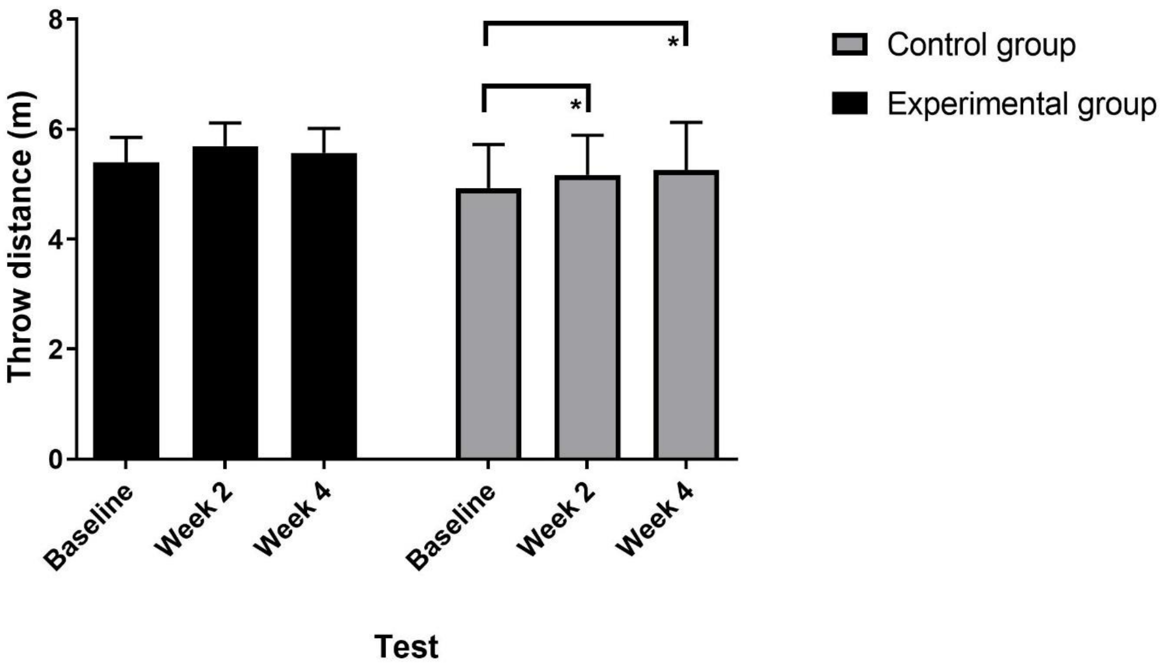

***Figure 8**: Change in upper body power for the experimental and control group across the 4-week training period. * represents significant differences, p< 0.05.*

4.2.5. Lower body muscle power

There was no significant difference in jump height across the four weeks for both the experimental [F (2, 7) = 0.42, p = 0.762] and control groups [F (2, 7) = 1.5, p = 0.287] (Figure 9).

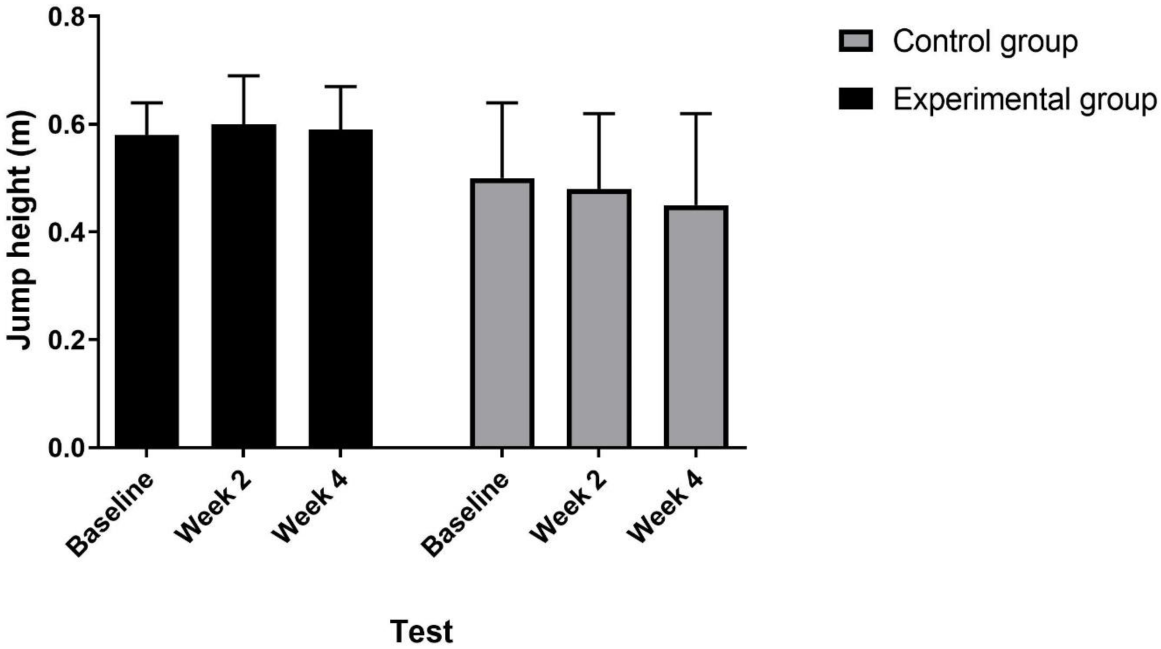

***Figure 9**: Change in leg power for the experimental and control group across the 4-week training period.*

4.2.6. Correlations

Bowling velocity correlation with other testing variables at baseline test

There was no significant correlation between velocity and jump height (r= 0.209, p= 0.376), throw distance (r= 0.230, p= 0.329), or bowling accuracy (r= -0.108, p= 0.649) for the baseline test (Figure 10).

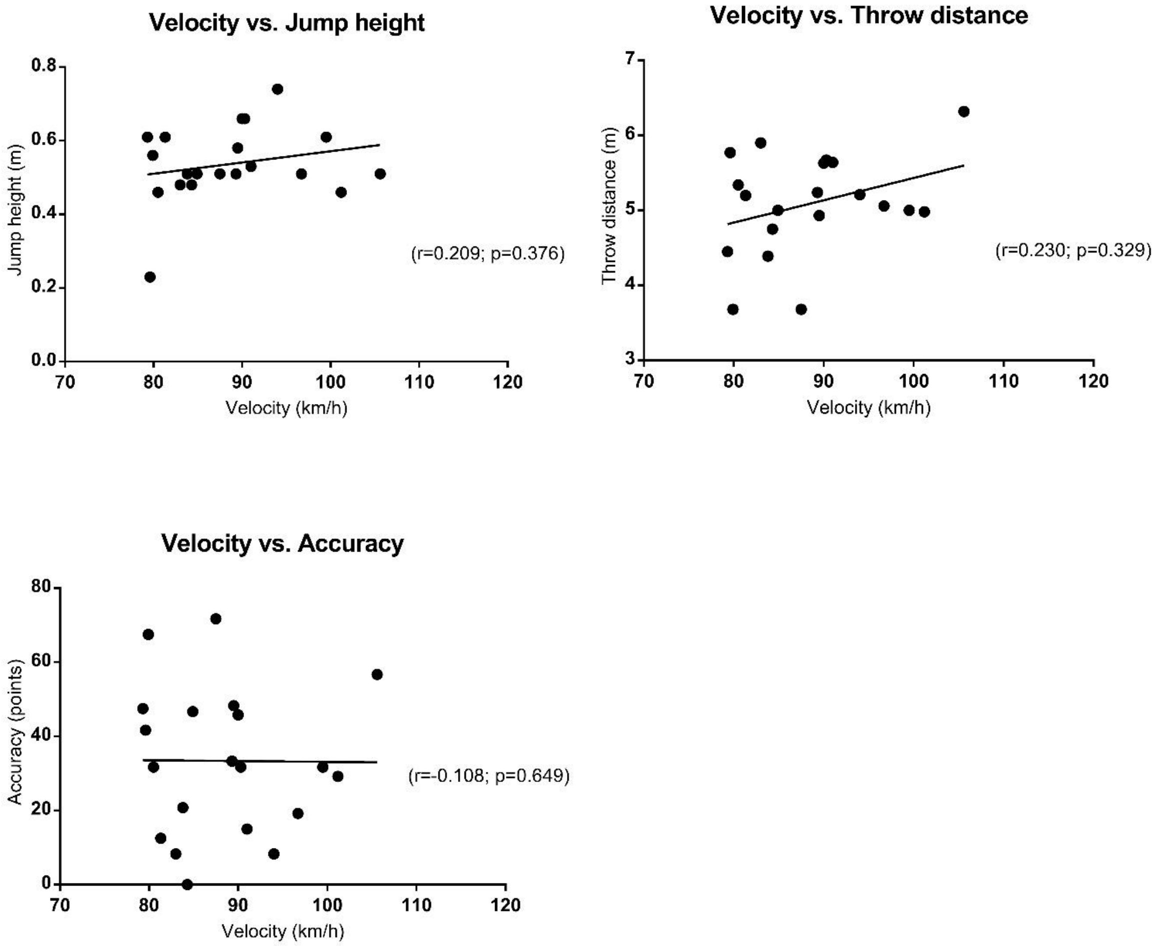

***Figure 10**: Correlation between velocity and jump height, throw distance, and accuracy*

Bowling velocity correlation with other testing variables after two weeks

There was a moderately positive significant correlation between bowling velocity and jump height (r= 0.503, p= 0.024) after two weeks. There was no significant correlation between bowling velocity and throw distance (r= 0.186, p= 0.433), nor between bowling velocity and accuracy (r= -0.267, p= 0.254) (**Figure 11**).

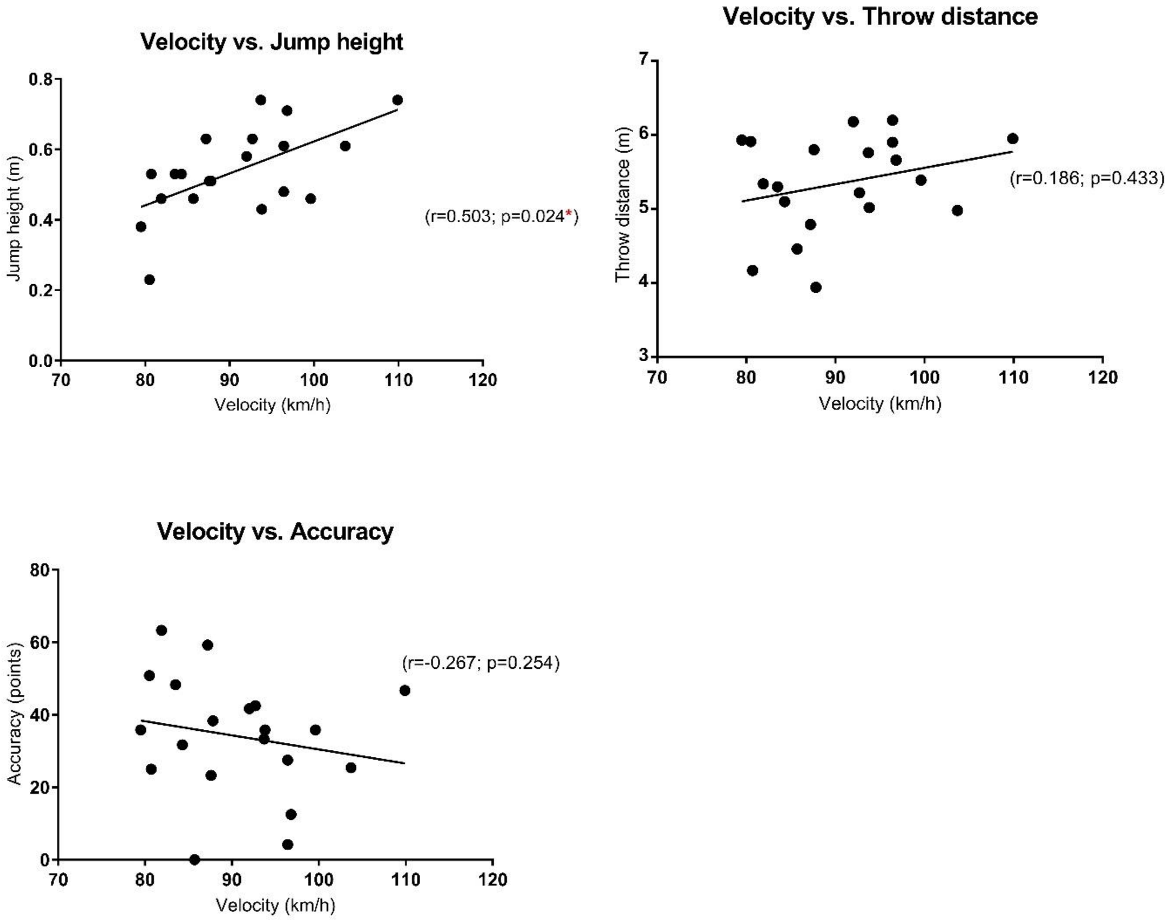

***Figure 11**: Correlation between velocity and jump height, throw distance, and accuracy. * represents significant correlation, p<0.05.*

Bowling velocity correlation with the other testing variables after four weeks

During the fourth test, there was another moderately positive significant correlation between bowling velocity and jump height (r= 0.570, p= 0.017). There was no significant correlation between bowling velocity and throw distance (r= 0.199, p= 0.427), nor between bowling velocity and bowling accuracy (r= -0.385, p= 0.114) (Figure 12).

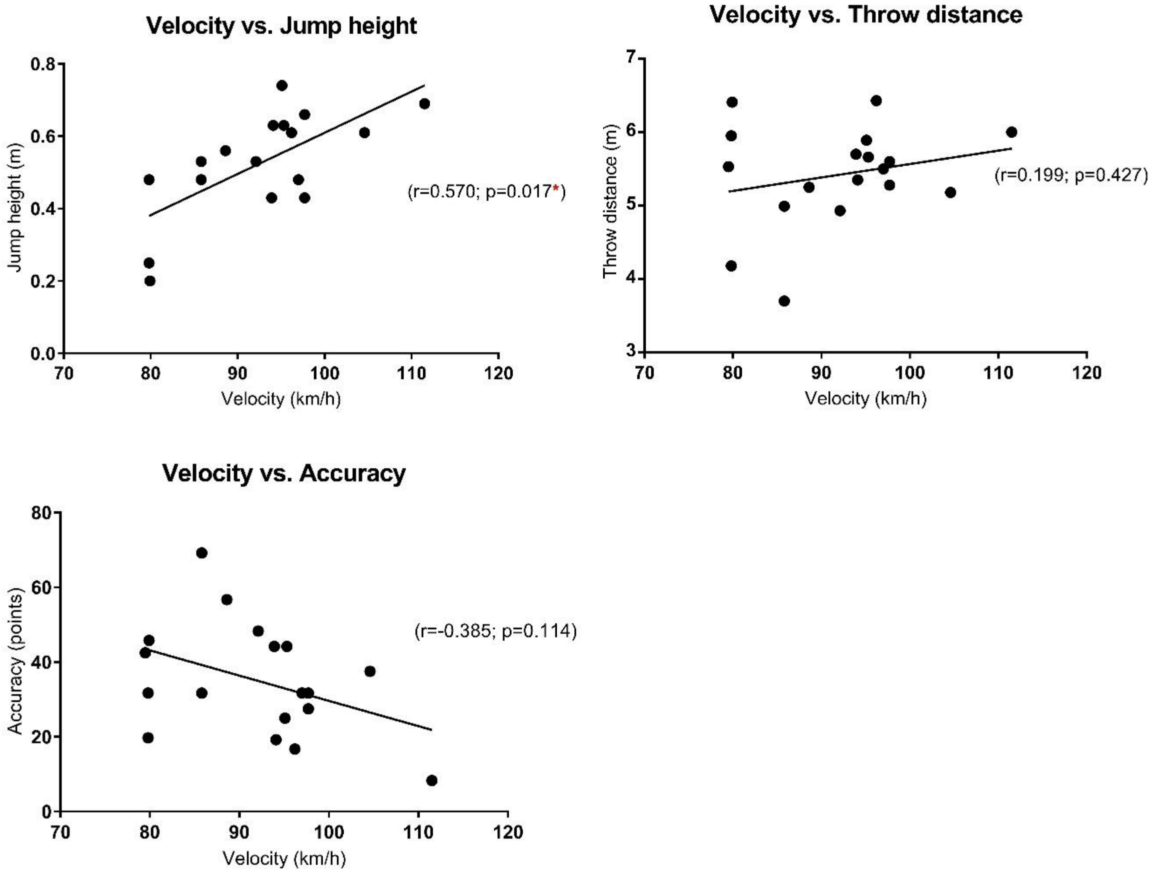

***Figure 12**: Correlation between velocity and jump height, throw distance, and accuracy. * represents significant correlation, p<0.05.*

4.2.7. Attendance adherence for the trial

An attendance adherence of 96% was reported (Table 10, 11).

***Table 10**: Summary of attendance adherence to trial for the experimental group*

Participant	Attendance week 1-2 (How many session attended out of 4 training sessions in 2 weeks)	Attendance week 3-4 (How many session attended out of 4 training sessions in 2 weeks)
1	4	4
2	4	2
3	4	3
4	4	4
5	4	2
6	4	4
7	4	4 (less intensity training)
8	4 (less intensity training)	4 (less intensity training)
9	4	4
Key: There were 4- training sessions per 2-week intervals. Complete attendance adherence = 4 for the weeks 1-2 and 4 for weeks 3-4.		

***Table 11**: Summary of attendance adherence to trial for the control group*

Participant	Attendance week 1-2 (How many session attended out of 4 training sessions in 2 weeks)	Attendance week 3-4 (How many session attended out of 4 training sessions in 2 weeks)
1	4	4
2	4	3
3	4	4
4	4	4
5	4	4
6	4	3
7	4	4
8	4	4
9	4	4
Key: There were 4- training sessions per 2-week intervals. Complete attendance adherence = 4 for the weeks 1-2 and 4 for weeks 3-4.		

CHAPTER FIVE

DISCUSSION

This chapter discusses the results obtained from the questionnaire and the experimental trial.

5.1. Questionnaire

Nearly 60% of participants stated that they did not have a gym membership. They attributed this to finding it too expensive or not having the time. Nevertheless, some tried to perform some sort of strength and power training at home, which indicates a keen interest in additional resistance training. The additional training time amounted to about 4 hours per week. It is not therefore surprising that 88% of the participants acknowledged that strength and power training was an important component of cricket bowling and yet only 39% of them had undergone some type of resistance training to try and increase their bowling velocity. It has been shown that regular training is required for the development of optimum fitness levels (Woolmer et al., 2008; Noakes & Durandt, 2000). However, 44% of fast bowlers reported that they did not do any type of strength training, attributing this to a lack of time and the high cost of gym membership.

5.2. Experimental trial

5.2.1. Velocity

Bowling velocity increased by 5km/h in the experimental group, while there was no change in the control group. This equates to a significant 6% increase after just four weeks of training ($p < 0.001$). The largest increase occurred after 2 weeks of training and equated to a mean of 4 km/h, with a non-significant 1km/h increase between weeks 2 and 4. In comparison with previous studies, the significant 5% increase in bowling velocity in the first two weeks ($p = 0.003$) is the largest increase in bowling velocity reported in such a short period. The final 6% increase in bowling velocity after the four weeks is also one of the biggest improvements found for any sporting code. Previous studies only started showing these results after six weeks of training (Gorostiaga et al., 1999; Powe & Deutsch, 2011; Escamilla et al., 2012). At any level of cricket, an increase in bowling velocity is of the utmost importance as it reduces the time available for the opposing batter to respond and play the most appropriate stroke. Coaches and scientists have widely advocated the importance of strength training and fitness for fast bowlers to improve their bowling velocity (Woolmer et al., 2008:249; Noakes & Durandt, 2000; Johnstone et al., 2014).

The notable increase in bowling velocity after just two weeks can be attributed to the neural adaptations that occurred in the first two weeks of resistance training. Brumitt & Cuddeford (2015) suggest that an immediate gain in strength takes place due to neural adaptations. Neural adaptations are the change in responsiveness of the sensory system to the change in stimulus. The role of these neural factors are strong in the early stages of strength training (Gabriel et al., 2006).

Another reason for the striking increase in bowling velocity could be muscle hypertrophy. Muscle hypertrophy refers to the increase in skeletal muscle size due to a growth in its components' cell size. Seynnes et al. (2007) report that muscle hypertrophy can take place after just two weeks of training. While Abe et al. (2000) reported a significant increase after six weeks, Abe et al. (2005) demonstrate that the total muscle volume can be significantly increased in just two weeks of resistance training. This result was replicated by DeFreitas et al. (2011), where an increase in muscle hypertrophy was shown after just one week. These hypertrophic changes can result in an increase in strength and endurance which enables an athlete to exert a greater force on different movements. In resistance training, neural adaptations occur before muscle hypertrophy and in some cases may be essential before hypertrophy takes place (Chilibeck et al., 1998). It has been suggested that a delay in hypertrophy is the result of a longer neural adaptation phase (Chilibeck et al., 1998).

In addition to the immediate increase in bowling velocity, there was a small (non-significant) increase in bowling speed between weeks 2 and 4. It is possible that the progressive overload after two weeks was not sufficient to elicit a significant change. In resistance training, the law of overload and principle of progressive overload states that overloading must continue to increase as adaptations occur to allow for improvement which can only occur when training overloads are above average (Sands et al., 2007), otherwise the training effect will plateau and further increases will not occur. The small increase between two and four weeks could have been due to an insufficient training overload. The principle of progressive overload suggests that one can overload through different variables. These variables include the amount of resistance used during the exercise, the volume of work being done (total number of sets and repetitions), rest intervals between sets and exercises, as well as training frequency (Kraemer & Ratamess, 2005). Therefore, an increase in any of these variables (or a decrease in rest intervals) would have been enough to produce a more successful overload. This also applies to overloading the resistance of the exercises performed rather than the number of repetitions or sets. This could have been done by having participants use heavier medicine balls for the plyometric (special resistance) exercises.

Overweighted and underweighted training has been used effectively to improve throwing velocity performance in different sporting activities. . The ideal percentage overload is important to obtain maximum benefit. In a previous bowling study, the ideal weighted implements might not have been used. Petersen et al. (2004) possibly used too low a percentage of weighted balls when they attempted to improve the ball velocity of their players. Their ball weights ranged between (±3% to ±16%) over a 10-week period. Only a 3.7% improvement in bowling velocity was achieved, even though they trained three times a week. The advantage of performing weighted implement training (specific resistance) is that it is a cricket bowling-specific method and optimises the full arm swing characteristic of cricket fast bowling. Any strength gains that might occur would be due to the training being conducted in accordance with the bowling movement. In this way, one is strengthening the power system in the arm that is required for the sport.

Petersen et al. (2004) suggest that more improvement can be made with a longer training programme, with more deliveries being bowled during sessions as well as an increase in weight ranges. However, this will increase the workload of the bowlers and predispose them to overuse injuries. The present study indicates that the length of the training programme can be reduced for amateur club players as they may have a greater capacity for change compared to elite players- provided the correct overload and resistance training exercises are chosen.

One of the main reasons for the success of this study is that it utilised all three resistance training methods. It combines general, special and specific resistance training methods to improve bowling velocity. A combination of dynamic core exercises, lower body exercises (squats, lunges, step-ups), as well as cricket-specific plyometric exercises was used. An additional advantage of the training protocol was that the duration was only four weeks. This is a relatively short time frame for any training study of this nature. Previous studies have featured programmes that lasted 6 weeks or longer (DeRenne et al., 1994; Petersen et al., 2004; Powe & Deutsch, 2011; Van den Tillaar & Marques, 2011b). Studies with a long duration of prescribed exercises have a negative effect on participant adherence to the programme (Bassett, 2003).

Another advantage to this type of training is that it is cost-effective, which is particularly important in the South African context for recreational players at club level. Many South Africans are socio-economically constrained, numbers of them previously disadvantaged by the political system. These players are unlikely to be able to afford access to expensive gym equipment to perform additional strength training. Furthermore, separate gym sessions are time-consuming and many club cricketers have other responsibilities that compete for their time. These include players having a full-time job, studying full time, or meeting family commitments. The basic training equipment used in this programme can easily be afforded by cricket clubs, or even the players themselves. The price of the modified weighted balls is the same as that of the regular balls (R100 per ball). The medicine ball (R400) is inexpensive, can be utilised by several players and will last for many years. The proposed programme is therefore cost effective, can be done within the usual training sessions, and will produce results comparable to studies of 6-10 weeks of training.

5.2.2. Accuracy

Bowling accuracy was measured to determine whether the training programme influenced accuracy over the 4-week period. Accuracy is an important aspect of bowling performance (Portus et al., 2000), both for taking wickets and for reducing the number of runs being scored by the opposing batter (Phillips et al., 2012). The speed and accuracy relationship is of the utmost importance as a delivery with high velocity has little value if it is delivered with poor accuracy (Freeston et al., 2007).

After four weeks, the increase in velocity did not happen at the expense of accuracy as there was no significant change in bowling accuracy in both groups. There was also no significant correlation between velocity and accuracy across the four weeks. Therefore, the improvement in bowling velocity among the experimental group would positively affect its members' bowling performance. Several previous studies conducted in sports like baseball pitching (Powe & Deutsch, 2011; DeRenne et al., 1994) and handball throwing (Van den Tillaar & Marques, 2011b) were flawed because they did not report accuracy. However, because of the importance of bowling accuracy in cricket, both Petersen et al. (2004) and Feros et al. (2013; 2016) reported measures of accuracy. In fact, these authors reported a decrease in accuracy. The reason for the decrease in accuracy in the study by Feros et al. (2013; 2016) could be the large weighted implements used (60% and 90%). The authors suggest the utilisation of the heavy-ball bowling could have changed the bowling motion pattern of the bowlers, thus leading to inconsistent delivery release points and poorer bowling accuracy (Feros et al., 2013; 2016). However, this argument does not apply to the results obtained by Petersen and collegues (2004), who used light-weighted implements (between 3% and 16%). Perhaps the reason could lie in the manner in which accuracy was measured by Petersen et al. (2004). They used a target zone on a pitch in terms of which deliveries that landed 6-7m from the stumps (the optimal zone was a determination of the length of the ball only) were considered successful, and the percentage of successful deliveries in three overs was used for data analysis. The accuracy system used in this study thus did not take the line of the delivery into account, hence rendering the validity of the accuracy measure open to question.

5.2.3. Upper body muscle power

For the experimental group, there was no change in upper body power, indicating that there was no increase in muscle power as measured by the seated medicine ball toss. This can be due to the fact that the medicine ball throw exercises used elbow extension as the main movement of the upper body however, the fast bowler is required to keep their elbow relatively straight (less than 15° extension). Therefore, the exercises used in the programme may not have been as effective. Furthermore, there was no significant correlation between upper body muscle power and bowling velocity. Taliep et al. (2003) similarly found no significant correlations between the medicine ball toss and bowling velocity in recreational fast bowlers. The fast bowling action uses a combined coordination of the fingers, arms, shoulders (Woolmer et al., 2008), as well as the erector spinae and lower back muscles (Forrest et al., 2016). These muscle groups are not congruent with those used in the seated medicine ball toss tests, as the chair limits the participant's use of his back and trunk muscles (Palao & Valdés, 2013), allowing only the arms and chest to be used. Similarly, the seated medicine ball toss test uses a concentric-eccentric contraction (Palao & Valdés, 2013) whereas the bowling movement consists of a concentric shoulder extension. Despite this, the regular seated medicine ball toss test was used because it is a valid and reliable measure of upper body power (Jones et al., 2016). More research should be done to identify a more appropriate upper body power test specifically for cricket, perhaps one centred on an action similar to bowling.

According to the literature reviewed, upper body power can also be measured by an overhead medicine ball throw, a sidearm medicine ball throw, the force-velocity power test and an upper body wingate anaerobic test. However, both the force-velocity power and upper body wingate anaerobic test require specialised equipment not available to the researcher. Additionally, the overhead and sidearm medicine ball throw test cannot be used because this throwing action is included as an exercise in the training protocol. If it were to be used, this could lead to familiarity with the exercise and result in a false upper body power measurement.

Unlike the case of the experimental group, there was a statistical significant increase in upper body muscle power in the control group. It is unclear why this was the case as they were not performing any resistance training during the trial. It is possible that there was a test familiarisation affect as the experiment group had a non-statistical significant increase in throw distance but a moderate effect size over the training period.

5.2.4. Lower body power

The results for both experimental and control groups indicated no change in lower body power across the four weeks. This finding is similar to that of Gorostiaga et al. (1999) and Hermassi et al. (2011), where there was no significant change in the countermovement jump test, despite there being a significant increase in throwing velocity.

There are number of possible reasons for this non-significant result. First, the number of lower body exercises in the training protocol was limited. Participants were only required to perform body weight squats and body weight split squats for 2 sets of 6-12 reps. The programme might therefore not have appropriately overloaded the muscles of the lower body. Overload can be obtained through increasing the weight load, increasing the number of repetitions or sets, decreasing the rest interval between sets and exercises, or even a combination thereof (Hass et al., 2001). Only the number of repetitions per set were increased by 10% from week 2 to week 4 in the current study. Perhaps it would have been more effective if the number of sets had also been increased.

Secondly, it is also possible that the countermovement jump height test is not the most appropriate test to measure lower body power in fast bowlers: it does not measure the power in the direction characteristic of bowling, nor does it mimic the bowling movement of the legs. The direction of power in the countermovement jump is upward on a vertical plane using two feet for take-off, whereas the direction of the power in the bowling action moving forward on a horizontal plane with a one-foot take-off. What is more, the countermovement jump test performed in this study involves a concentric-eccentric contraction (Palao & Valdés, 2013) while the bowling movement utilises various lower limb actions of knee flexion or knee extension, or a combination of the two (Portus et al., 2004). Despite this, the regular countermovement jump test was used because it is a valid and reliable measure of lower body power (Pyne et al., 2006).

Other ways to measure lower body power would be to use the standing long jump test, the squat jump test and a force-velocity power test. However, neither of the jump tests are appropriate for measuring lower body power in cricketers because they do not mimic the bowling leg action. The jump tests are performed from a stationary position whereas the bowling action requires a run up. Further, these tests do not require the same knee flexion/extension as used in cricket. It seems that more research should be done to identify a more appropriate lower body power test specifically for cricket, utilising a similar knee flexion/extension as used in the bowling action. Finally, the force-velocity power test could not be used because it required specialised equipment unavailable to the researchers.

An interesting finding made by this study was that there was a significant positive correlation between lower body power and velocity in the second and fourth weeks for the pooled groups, which indicates a moderately positive correlation between lower body power and bowling velocity. This replicates results showing that throwing velocity is moderately related to the peak power of the lower limbs in handball (Chelly et al., 2010); and also in water polo (McCluskey et al., 2010), where lower body power was a significant predictor of higher throwing velocity.

Despite there being no change in lower body power, the correlation between lower body power and bowling velocity replicates that found by Pyne et al. (2006) in senior cricketers. Furthermore, faster bowlers have shown to have lower countermovement jump measures.

5.2.5. Limitations

There are a number of limitations to the study. First, because three different types of resistance training methods were used, it is not possible to pinpoint which type of training method is most effective or which contributes most to the increase in bowling velocity. However, it was not the purpose of the study to determine which training method would be most effective. The aim was to determine how a combination of the three methods can be used to improve bowling velocity in the shortest period of time using minimal equipment. Further, perhaps individually, these programmes don't' warrant significant findings. More research can be done on this.

Secondly, the training programme could have increased the power in the upper body, resulting in an increase in the velocity of the arm, hand and/or shoulder complex during bowling. However, this was not measured. Further, in increase in upper body power found in the control group can simply be due to participating in cricket as these participants are inexperienced and untrained.

Thirdly, both measures of power (countermovement jump test and seated medicine ball toss test) are not the most appropriate due to them not being cricket-specific. More research is required to develop tests (for upper and lower body power) that mimic the action of bowling, in order to provide a true reflection of the power of the player.

Fourthly, it is inferred that the overload in the general and special resistance exercises was insufficient. This could have been remedied by increasing the resistance of the exercises by adding more weight, increasing the number of sets or by decreasing the rest periods between sets and exercises. No rest periods were specified in the programme.

Fifthly, all the medicine ball throw exercises used elbow extension as the main movement of the upper body however, the fast bowler is required to keep their elbow relatively straight (less than 15° extension). Future research could look at incorporating exercises where there is less than 15° of straightening.

Sixthly, in order to see whether the resistance training has an effect, the time spent training needs to be the same in both experimental and control groups. Future studies could see the control group participating in a programme that is unlikely to improve their power and bowling velocity- such as a stretching programme. Additionally, the warm-up performed by participants before testing procedures should be standardized for future studies as the number of balls bowled during the warm up may influence velocity and accuracy.

Seventhly, it was not considered whether participants were already on a strength training programme before the study took place. This could have potentially impacted the results of the study.

Eighthly, it is important to note that the mean age of the participants in the control group is higher than the experimental group (although not significantly different [p = 0.069]) which could possibly affect the trainability of the athletes.

Lastly, the small sample size is a limitation. Twenty participants were recruited and only 18 completed the trial. The sample size was limited by the number of fast bowlers available for recruitment. After an exhausting recruitment process (contacting all clubs in the 1st and 2nd Division), 49 participants completed the questionnaire. Of these, 9 were injured and excluded from recruitment for the experimental protocol. Finally, only 20 participants (50% of the available population) volunteered for the trial. Small sample sizes increase the chances of type 2 error (incorrectly accepting the null hypothesis by concluding there are no differences when in fact there are real differences (O'Donoghue, 2012). Despite this, a significant difference was obtained for velocity over the four weeks, which further strengthens the argument that the training programme was effective. Further, no exact count was taken to determine how many questionnaires were sent out compared to how many was completed. Therefore, the 49 participants who completed the questionnaire was less than the available sample of fast bowlers in club cricket.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Overview

The primary aim of this study was to develop and test a training programme that could effectively improve bowling speed. The training programme was based on the results of a questionnaire administered to the participants, and on relevant precedents reported in the literature. The programme had to be cost-effective, utilise a number of different resistance training methods with minimal risk of injury to the participants, be performed in a minimal period of time with minimal repetitions, and be capable of being incorporated into the regular cricket training sessions.

The results of the questionnaire showed that many players at club level cannot afford a gym membership or do not have the time to attend gym (even though they may have a membership). The programme was therefore specifically designed to be done on field during normal training hours. The objective was to improve bowling performance without spending too much money or time on formal (gym) training. This is essential for club-level cricket players and coaches who are looking for cost-effective ways to improve fast bowling performance.

The results indicate that a four-week resistance training programme consisting of a combination of core and lower body exercises (squats, lunges, step-ups) as well as cricket-specific plyometric exercises and weighted implement training significantly improved bowling velocity by 6%. Furthermore, there was no change in the accuracy of the deliveries. These results show that it is possible to improve one's bowling performance in a short period of time. Previous studies have reported an increase in bowling velocity, but at the expense of bowling accuracy, and after a longer period of time (Petersen et al., 2004; Feros et al., 2016). These studies reported a 4km/h and 3km/h increase, after 10 and 8 weeks respectively. Moreover, both studies found a decrease in bowling accuracy.

The short duration of the training protocol is another benefit, as it will enable fast bowlers to improve their performance within a limited period of time. The training protocol did not induce any injury and is therefore safe to administer.

Considering these results, the following conclusions can be drawn in relation to the original hypotheses:

Hypothesis 1: A rejection of the null hypothesis ($p<0.05$).

The results of this study lead to the acceptance of the alternative hypothesis as follows: there was a significant increase in bowling velocity after four weeks.

Hypothesis 2: A rejection of the null hypothesis ($p<0.05$).

The results of this study lead to the acceptance of the alternative hypothesis as follows: there was no change in bowling accuracy after four weeks.

Hypothesis 3: An acceptance of the null hypothesis.

The results of this study lead to the rejection of the alternative hypothesis as follows: there was no significant increase in upper body power after four weeks.

Hypothesis 4: An acceptance of the null hypothesis.

The results of this study lead to the rejection of the alternative hypothesis as follows: there was no significant increase in lower body power after four weeks.

6.2. Recommendations

It is recommended that club-level bowlers follow the outlined programme but under strict supervision of a trained investigator or professional strength and conditioning coach.

Future research should manipulate the overload of the various exercises in the third and fourth weeks. This should help to further increase bowling velocity and prevent a plateau if implemented correctly, as long as not to induce an unnecessary overload that may predispose players to injury. This overload can be achieved by precise elevations in resistance and load of the exercises by adding weights to the general resistance exercises or increasing the intensity of the exercises. Specified rest periods between sets and exercises can also be modulated and included in the programme. This will ensure that all players rest for the same length of time and have an adequate period for recovery before performing the next set or exercise. Additionally, the length of these rest periods can be reduced as another method of overload. A final consideration for future research is to have a rest period after the four weeks of training have been completed, then continue with a heavier/lighter range of balls (i.e. 15-25%).

REFERENCES

Abe, T., DeHoyos, D. V, Pollock, M.L. & Garzarella, L. 2000. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *European journal of applied physiology*, 81(3): 174–80.

Abe, T., Yasuda, T., Midorikawa, T., Sato, Y., Kearns, C.F., Inoue, K., Koizumi, K. & Ishii, N. 2005. Skeletal muscle size and circulating IGF-1 are increased after two weeks of twice daily “KAATSU” resistance training. *International Journal of KAATSU Training Research*, 1(1): 6–12.

Almuzaini, K.S. & Fleck, S.J. 2008. Modification of the standing long jump test enhances ability to predict anaerobic performance. *Journal of Strength and Conditioning Research*, 22(4): 1265–1272.

Anshel, M.H. & Seipel, S.J. 2009. Self-monitoring and selected measures of aerobic and strength fitness and short-term exercise attendance. *Journal of Sport Behavior*, 32(2): 125–151.

Barata, J. 1992. Changes in ball velocity in the handball free throw, induced by two different speed-strength training programs. *Motricidade Humana*, 8(1): 45–55.

Bassett, S.F. 2003. The assessment of patient adherence to physiotherapy. *New Zealand Journal of Physiotherapy*, 31(July): 60–66.

Bloomfield, J., Blanksby, B.A., Ackland, T.R. & Allison, G.T. 1990. The Influence of Strength Training on Overhead Throwing Velocity of Elite Water Polo Players. *Australian Journal of Science and Medicine in Sport*, 22(3): 63–67.

Brumitt, J. & Cuddeford, T. 2015. Current Concepts of Muscle and Tendon Adaptation To Strength and Conditioning. *International Journal of Sports Physical Therapy*, 10(6): 748–759.

Cadmus-bertram, L., Irwin, M., Alfano, C., Campbell, K., Duggan, C., Foster-schubert, K., Wang, C. & Mctiernan, A. 2014. Predicting Adherence of Adults to a 12-Month Exercise Intervention. *Journal of Physical Activity and Health*, 11: 1304–1312.

Chelly, M.S., Hermassi, S. & Shephard, R.J. 2010. Relationships Between Power and Strength of the Upper and Lower Limb Muscles and Throwing velocity in Male Handball Players. *Journal of Strength and Conditioning Research*, 24(6): 1480–1487.

Chilibeck, P.D., Calder, a W., Sale, D.G. & Webber, C.E. 1998. A comparison of strength and muscle mass increases during resistance training in young women. *European journal of applied physiology and occupational physiology*, 77: 170–175.

Clemons, J.M., Campbell, B. & Jeansonne, C. 2010. Validity and reliability of a new test of upper body power. *J Strength Cond Res*, 24(6): 1559–1565.

Cricket Lab. 2016. Cricket Fitness: Plans and Programmes. http://www.cricketlab.co/cricket-fitness.html 27 August 2018.

Cricket South Africa. 2018. Super 6 Preventative Exercises For The Shoulder.

Davies, R., du Randt, R., Venter, D. & Stretch, R. 2008. Cricket : Nature and incidence of fast-bowling injuries at an elite , junior level and associated risk factors. *South African Journal of Sports Medicine*, 20(4): 115–118.

Davison, S.W., Caruso, J.F., Taylor, S.T., Lutz, B.M., Olson, N.M., Mason, M.L. & Szymanski, D.J. 2010. The Benefits of Low-Friction Resistance Training in an Adolescent Baseball Player. *Medicina Sportiva*, 14(2): 90–95.

DeFreitas, J.M., Beck, T.W., Stock, M.S., Dillon, M.A. & Kasishke, P.R. 2011. An examination of the time course of training-induced skeletal muscle hypertrophy. *European Journal of Applied Physiology*, 111(11): 2785–2790.

DeRenne, C., Buxton, B.P., Hetzler, R.K. & Ho, K.W. 1994. Effects of Under- and Overweighted Implement Training on Pitching Velocity. *Journal of Strength and Conditioning Research*, 8(4): 247–250.

DeRenne, C., Ho, K. & Murphy, J. 2001. Effects of general, special, and specific resistance training on throwing velocity in baseball: A brief review. *Journal of Strength & Conditioning Research*, 15(1): 148–156.

DeRenne, C., Ho, K.W. & Blitzblau, A. 1990. Effects of Weighted Implement Training on Throwing Velocity. *Journal of Strength and Conditioning Research*, 4(1): 16–19.

DeRenne, C., House, T. & Harris, T.W. 1993. *Power baseball*. West Publishing Company.

DeRenne, C., Tracy, R. & Dunn-Rankin, P. 1985. Increasing throwing velocity. *Athletic Journal*, 65(9): 36–39.

Edwards Van Muijen, A., Joris, H., Kemper, H. & Jan Van Ingen Schenau, G. 1991. Throwing practice with different ball weights: Effects on throwing velocity and muscle strength in female handball players. *Research in Sports Medicine: An International Journal*, 2: 103–113.

Escamilla, R.F., Ionno, M., DeMahy, M.S., Fleisig, G.S., Wilk, K.E., Yamashiro, K., Mikla, T., Paulos, L. & Andrews, J.R. 2012. Comparison of Three Baseball-Specific 6-Week Training Programs on Throwing Velocity in High School Baseball Players. *Journal of Strength and Conditioning Research*, 26(7): 1767–1781.

Escamilla, R.F., Speer, K.P., Fleisig, G.S., Barrentine, S.W. & Andrews, J.R. 2000. Effects of throwing overweight and underweight baseballs on throwing velocity and accuracy. *Sports Medicine*, 29(4): 259–272.

Escamilla, R.F., Yamashiro, K., Fleisig, G.S., Mikla, T., Dunning, R., Paulos, L. & Andrews, J.R. 2010. Effects of 4-week Youth Baseball Conditioning Program on Throwing Velocity. *Journal of Strenght and Conditioning Research*, 24(12): 3247–3254.

Feros, S.A., Young, W.B. & O'Brien, B.J. 2019. Efficacy of Combined General, Special, and Specific Resistance Training on Pace Bowling Skill in Club-Standard Cricketers. *The Journal of Strength & Conditioning Research*, 00(00): 1–12.

Feros, S.A., Young, W.B. & O'Brien, B.J. 2013. The Acute effects of heavy-ball bowling on fast bowling performance in cricket. *Journal of Australian Strength and Conditioning*, 21: 41–44.

Feros, S.A., Young, W.B. & O'Brien, B.J. 2016. The Effects of Combined General, Special, and Specific Resistance Training on Pace Bowling Speed and Accuracy. *Journal of Australian Strength & Conditioning*, 24(6): 17.

Fleck, S.J. & Kraemer, W. 2014. *Designing Resistance Training Programs, 4E*. Human Kinetics.

Fleisig, G.S., Phillips, R., Shatley, A., Loftice, J., Dun, S., Drake, S., Farris, J.W. & Andrews, J.R. 2006. Kinematics and kinetics of youth baseball pitching with standard and lightweight balls. *Sports Engineering*, 9(3): 155–163.

Forrest, M., Hecimovich, M. & Dempsey, A. 2016. Lumbopelvic muscle activation patterns in adolescent fast bowlers. *European Journal of Sport Science*, 16(6): 677–684.

Freeston, J., Ferdinands, R. & Rooney, K. 2007. Throwing velocity and accuracy in elite and sub-elite cricket players: A descriptive study. *European Journal of Sport Science*, 7(4): 231–237.

Freeston, J. & Rooney, K. 2008. Progressive velocity throwing training increases velocity without detriment to accuracy in sub-elite cricket players : A randomized controlled trial. *European Journal of Sport Science*, 8(6): 373–378.

Gabriel, D.A., Kamen, G. & Frost, G. 2006. Neural adaptations to resistive exercise: Mechanisms and recommendations for training practices. *Sports Medicine*, 36(2): 133–149.

Gelen, E., Dede, M., Bingul, B.M., Bulgan, C. & Aydin, M. 2012. Acute effects of static stretching, dynamic exercises, and high volume upper extremity plyometric activity on tennis serve performance. *Journal of Sports Science and Medicine*, 11(4): 600–605.

Gorostiaga, E.M., Izquierdo, M., Iturralde, P., Ruesta, M. & Ibáñez, J. 1999. Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. *European Journal of Applied Physiology and Occupational Physiology*, 80: 485–493.

Guinness World Records. 2018. Fastest baseball pitch (male). http://www.guinnessworldrecords.com/world-records/fastest-baseball-pitch-(male)/ 9 November 2018.

Hass, C.J., Feigenbaum, M.S. & Franklin, B.A. 2001. Prescription of Resistance Training for Healthy Populations. *Sports Medicine*, 31(14): 953–964.

Hawley, J.A. 2008. Specificity of training adaptation: Time for a rethink? *Journal of Physiology*, 586(1): 1–2.

Haynes, R.B. 2001. Improving patient adherence: state of the art, with a special focus on medication taking for cardiovascular disorders. *Compliance in healthcare and research. Armonk, NY: Futura Publishing*: 3–21.

Hermassi, S., Chelly, M.S., Fathloun, M. & Shephard, R.J. 2010. The Effect of Heavy- vs. Moderate-Load Training on the Development of Strength, Power, and Throwing Ball Velocity in Male Handball Players. *Journal of Strength and Conditioning Research*, 24(9): 2408–2418.

Hermassi, S., Chelly, M.S., Tabka, Z., Shepard, R.J. & Chamari, K. 2011. Effects of 8-week in-season upper and lower limb heavy resistence training on the peak power, throwing velocity, and sprint Performance of Elite Male Handball Players. *Journal of Strength and Conditioning Research*, 25(9): 2424–2433.

Hill, A. V. 1938. The Heat of Shortening and the Dynamic Constants of Muscle. *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 126(843): 136–195.

Johnson, B.L. & Nelson, J.K. 1979. *Practical Measurements for evaluation in physical education*. Minnesota: BurgessPublishing Company.

Johnstone, J.A., Mitchell, A.C.S., Hughes, G., Watson, T., Ford, P.A. & Garrett, A.T. 2014. The athletic profile of fast bowling in cricket: a review. *Journal of strength and conditioning research*, 28(5): 1465–1473.

Jones, M., R Martin, J., Jagim, A. & Oliver, J. 2016. Effect of Direct Whole-Body Vibration on Upper-Body Muscular Power in Recreational, Resistance-Trained Men. *Journal of Strength and Conditioning Research*, 31: 1.

King, A.C. 1994. Clinical and community interventions to promote and support physical activity participation. In *Advances in Exercise Adherence*. Champaign, IL: Human Kinetics Publishers: 183–

212.

Knudson, D. V. 2009. Correcting the use of the term 'power' in the strength and conditioning literature. *Journal of strength and conditioning research*, 23(6): 1902–1908.

Kraemer, W.J. & Ratamess, N.A. 2005. Progression and Resistance Training. *Research Digest*, 6(3): 1–8.

Larsson, P. 2018. All-time men's best 100m. http://www.alltime-athletics.com/m_100ok.htm 11 November 2018.

Lin, Y.-T. & Chang, C. 2008. Monitoring the training effect in different periods in elite athletes. *International Journal of Sport and Exercise Science*, 1(1): 15–21.

Linthorne, N.P. 2000. Optimum take-off range in vertical jumping. In *Book of Abstracts, 3rd Australasian Biomechanics Conference, Griffith University, Brisbane, Australia*. 49–50.

Litwhiler, D. & Hamm, L. 1973. Overload: Effect on throwing velocity and accuracy. *Athletic Journal*, 53(5): 64–65.

Manchado, C., García-Ruiz, J., Cortell-Tormo, J.M. & Tortosa-Martínez, J. 2017. Effect of Core Training on Male Handball Players' Throwing Velocity. *Journal of Human Kinetics*, 56(1): 177–185.

Marcus, B.H., Forsyth, L.H., Stone, E.J., Dubbert, P.M., McKenzie, T.L., Dunn, A.L. & Blair, S.N. 2000. Physical activity behavior change: Issues in adoption and maintenance. *Health Psychology*, 19(1, Suppl): 32–41.

Markovic, G., Dizdar, D., Jukic, I. & Cardinale, M. 2004. Reliability and factorial validity of squat and counter movement jump tests. *Journal of Strength & Conditioning Research*, 18(3): 551–555.

Marlatt, G.A. & George, W.H. 1998. *Relapse prevention and the maintenance of optimal health.* New York: Springer Publishing Co.

McCluskey, L., Lynskey, S., Leung, C.K., Woodhouse, D., Briffa, K. & Hopper, D. 2010. Throwing velocity and jump height in female water polo players: Performance predictors. *Journal of Science and Medicine in Sport*, 13(2): 236–240.

McEvoy, K.P. & Newton, R.U. 1998. Baseball Throwing Speed and Base Runnin Speed: The Effects of Ballistic Resistance Training. *Journal of Strength and Conditioning Research*, 12(4): 216–221.

Murtaza, S.T., Mohd, I., Mohd, S., Ahmad, T., Jabin, F., Katiyar, A.K., Ahmad, S., Singh, R.P., Bhat, A.H., Khan, S.A., Bhat, R.A., Malik, I.M., Naikoo, S.A., Zakir, M., Sabir, M., Ahmad, I., Chandra, S., Kumari, L., Khan, T., Al, As., Rizwan, Q., Ali, I. & Singh, V.K. 2014. Development of Cricket- Specific Bowling Accuracy Test. *Academic Sports Scholar*, 3(11): 1–4.

Myers, L. & Midence, K. 1998. *Adherence to treatment in medical conditions*. Amsterdam, Netherlands: Harward Academic Publishers.

Nash, A. 2008. Seated Medicine Ball Toss as a Predictor of Upper-Body Strength in Untrained Women. *Kentucky Newsletter for Health, Physical Education, Recreation & Dance*, 44(2): 27–30.

National Council on Strength and Fitness. 2015. Youth Training – Resistance Training for Optimal Neuromuscular Development. https://www.ncsf.org/blog/167-youth-training–resistance-training-optimal-neuromuscular-development 16 September 2018.

Newton, R.U. & McEvoy, K.P. 1994. Baseball throwing velocity: A comparison of medicine ball training and weight training. *Journal of Strength and Conditioning Research*, 8(3): 198–203.

Noakes, T.D. & Durandt, J. 2000. Physiological requirements of cricket. *Journal of Sports Sciences*, 18: 919–929.

O'Donoghue, P. 2012. *Statistics for Sport and Exercise Studies: An Introduction*. New York: Routledge.

Orchard, J.W., Blanch, P., Paoloni, J., Kountouris, A., Sims, K., Orchard, J.J. & Brukner, P. 2015. Fast bowling match workloads over 5-26 days and risk of injury in the following month. *Journal of Science and Medicine in Sport*, 18(1): 26–30.

Palao, J.M. & Valdés, D. 2013. Testing protocol for monitoring upper-body strength using medicine balls. *Journal of Human Sport and Exercise*, 8(2): 334–341.

Petersen, C.J., Wilson, B.D. & Hopkins, W.G. 2004. Effects of modified-implement training on fast bowling in cricket. *Journal of Sports Sciences*, 22(October 2013): 1035–1039.

Phillips, E., Portus, M., Davids, K. & Renshaw, I. 2012. Performance accuracy and functional variability in elite and developing fast bowlers. *Journal of Science and Medicine in Sport*, 15(2): 182–188.

Portus, M., Sinclair, P.J., Burke, S.T., Moore, D.J. & Farhart, P.J. 2000. Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sports Sciences*, 18(12): 999–1011.

Portus, M.R., Mason, B.R., Elliott, B.C., Pfitzner, M.A.X.C. & Done, R.P. 2004. Technique Factors Related to Ball Release Speed and Trunk Injuries in High Performance Cricket Fast Bowlers. *Sports Biomechanics*, 3(2): 263–284.

Portus, M.R., Sinclair, P.J., Burke, S.T., Moore, D.J. & Farhart, P.J. 2000. Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sports Sciences*, 18(12): 999–1011.

Powe, T. & Deutsch, J. 2011. Overload / Underload Training : A Look into Weighted Baseball Throwing.

Missouri Association for Health, Physical Education, Recreation and Dance Journal, 21: 102–106.

Pretz, R. 2004. ''Ballistic Six" Plyometric Training for the Overhead Throwing Athlete. *Strength and Conditioning Journal*, 26(6): 62–66.

Prokopy, M.P., Ingersoll, C.D., Nordenschild, B., Katch, F.I., Gaesser, G.A. & Weltman, A. 2008. Closed-kinetic chain upper body training improves throwing performance of NCAA division 1 softball players. *Journal of Strength and Conditioning Research*, 22(6): 1790–1798.

Pyne, D.B., Duthie, G.M., Saunders, P.U., Petersen, C.A. & Portus, M.R. 2006. Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *Journal of Strength and Conditioning Research*, 20(3): 620–626.

Quinn, E. & Fogoros, R. 2018. Scientific Rules That Lead to Fitness. https://www.verywellfit.com/the-6-scientific-rules-you-must-follow-to-get-fit-3120111 15 September 2018.

Rand, C.S. & Weeks, K. 1998. *Measuring adherence with medication regimens in clinical care and research.* New York: Springer Publishing Co.

Samozino, P., Morin, J., Hintzy, F. & Belli, A. 2008. A simple method for measuring force, velocity and power output during squat jump. *Journal of Biomechanics*, 41: 2940–2945.

Sands, W., Stone, M. & E Stone, M. 2007. *Principles and Practice of Resistance Training*. Champaign, IL: Human Kinetics Publishers.

Seynnes, O.R., Boer, M. De & Narici, M. V. 2007. Hormonal responses and adaptations to resistance exercise and training. *Journal of Applied Physiology*, 102: 368–373.

Singh, A., Gopal, A. & Sandhu, J. 2014. The effect of 'Ballistic Six' plyometric training on performance of medium pace Asian Indian cricket bowlers. *Saudi Journal of Sports Medicine*, 14(2): 94.

Soomro, N., Hackett, D., Freeston, J., Blanch, P., Kountouris, A., Dipnall, J., Lyle, D. & Sanders, R. 2018. How do Australian coaches train fast bowlers? A survey on physical conditioning and workload management practices for training fast bowlers. *International Journal of Sports Science and Coaching*, 0(0): 1–10.

Straub, W.F. 1968. Effect of overload training procedures upon velocity and accuracy of the overarm throw. *Research Quarterly. American Association for Health, Physical Education and Recreation*, 39(2): 370–379.

Szymanski, D.J. 2012. Effects of Various Resistance Training Methods on Overhand Throwing Power Athletes. *Strength and Conditioning Journal*, 34(6): 61–74.

Szymanski, D.J. 2007. Resistance Training to Develop Increased Bat Velocity. *NSCA's Performance*

Training Journal, 6(2): 16–20.

Szymanski, D.J., DeRenne, C. & Spaniol, F. 2009. Contributing Factors for Increased Bat Swing Velocity. *Journal of Strength and Conditioning Research*, 23(4): 1338–1352.

Taliep, S., Gray, J., St Clair Gibson, A., Calder, S., Lambert, M. & Noakes, T. 2003. The effects of a 12-over bowling spell on bowling accuracy and pace in cricket fast bowlers. *Journal of Human Movement Studies*, 45: 197–217.

Taylor, A.H. & May, S. 1996. Threat and coping appraisal as determinants of compliance with sports injury rehabilitation : an application of Protection Motivation Theory. *Journal of Sports Sciences*, 14: 471–482.

Tennis Companion. 2018. The World's Fastest Men's & Women's Tennis Serves Ever Recorded. https://tenniscompanion.org/fastest-tennis-serves/ 9 November 2018.

Van Den Tillaar, R. 2004. Effect of different training programs on the velocity of overarm throwing- a brief review. *Journal of Strength and Conditioning Research*, 18(2): 388–396.

Van Den Tillaar, R. & Ettema, G. 2011. A comparison of kinematics between overarm throwing with 20% underweight, regular, and 20% overweight balls. *Journal of Applied Biomechanics*, 27(3): 252–257.

van den Tillaar, R. & Marques, M. 2011. Effect of training on the kinematics and performance in overarm throwing in experienced female handball players. *Portuguese Journal of Sport Sciences*, 11(2): 125–128.

van den Tillaar, R. & Marques, M.C. 2011. A comparison of Three Training Programs with the same Workload on Overhead Throwing Velocity with Different Weighted Balls. *Journal of Strength and Conditioning Research*, 25(8): 2316–2321.

Van den Tillaar, R. & Marques, M.C. 2009. Effect of Two Different Training Programs with the Same Workload on Soccer Overhead Throwing Velocity. *Journal of Strenght and Conditioning Research*, 4: 474–484.

van den Tillar, R. & Marques, M. 2011. Effect of training on ball release velocity and kinematics in overarm throwing among experienced female handball players. *Kinesiologia Slovenica*, 46(2): 38–46.

Total Sportek. 2017. 10 Fastest Bowlers In Cricket History (Records). https://www.totalsportek.com/cricket/fastest-bowlers-of-all-times/ 9 November 2018.

Weber, J. & Wertheim, E.H. 1989. Relationships of Self-Monitoring, Special Attention, Body Fat

Percent, and Self-Motivation to Attendance at a Community Gymnasium. *Journal of sport & exercise psychology*, 11: 105–114.

Wickington, K.L. & Linthorne, N.P. 2017. Mechanics in Cricket Fast Bowling. *MDPI Sports*, 5(18): 1–14.

Wooden, M.J., Greenfield, B., Johanson, M., Litzelman, L., Mundrane, M. & Donatelli, R.A. 1992. Effects of strength training on throwing velocity and muscle shoulder performance in teenage baseball players. *Journal of Orthopaedic and Sports Physical Therapy*, 15: 223–228.

Woolmer, B., Noakes, T. & Moffett, H. 2008. *Bob Woolmer's Art and Science of Cricket*. Cape Town; London: Struik ; New Holland [distributor].

Wormgoor, S., Harden, L. & Mckinon, W. 2010. Anthropometric, biomechanical, and isokinetic strength predictors of ball release speed in high-performance cricket fast bowlers. *Journal of Sports Sciences*, 28(9): 957–965.

APPENDIX A

Informed consent – Experimental group

Informed consent – Control group

INFORMED CONSENT: EXPERIMENTAL GROUP

I, ____ , have been fully informed about the nature of this research and hereby give my consent to act as a participant for the research. I also give consent for all data collected to be made available for research purposes.

Background:

The aim of this study is to investigate if training with a combination of overweight, underweight and regular cricket balls as well as power training with a medicine ball could affect cricket bowling speed.

Purpose and benefits:

Velocity is an important aspect of sport including cricket bowling. However, very few research studies have been done in order to maximise this aspect through a combination of weighted implement training and medicine ball training. A combination of such training could help benefit the fast bowler by increasing his bowling speed as well as increasing his strength without having to do any additional strength training outside of cricket practice.

Testing procedure:

The testing procedure consists of two parts:

1. Answering a questionnaire based on their training load and availability to train as well as help the study to understand whether participants have free time, and/or the finances to do strength training at home or at the gym.
2. Record performance data during test sessions after participating in weighted implement and strength training (experimental group).

Risks to participants:

The risks associated with the involvement as a participant in this study would be no different to cricket bowling in a normal net practice or match situation. If any adverse effects do occur, participants will be referred to a medical doctor.

Benefits to participants:

Participants will not be paid for their participation in the study trial but will be able to keep possession of cricket balls given to them to be used during the study trial. Participants will also be able to use the study trial as extra bowling practice. In addition, all results will be distributed in a simple written report and participants will be allowed to ask questions and can receive feedback upon request.

Privacy:

I understand that my anonymity is ensured in any publication of data and will be coded for analysis to enhance my safety and confidentiality and that all data generated from the study trial will be stored and analysed in a manner that maintains my confidentiality. I am aware that I have the right to withdraw from the study trial at any stage without stating a reason and without prejudice.

Participant:______________________________Signature:____________________Date:______________

Researcher:______________________________Signature:____________________Date:______________

INFORMED CONSENT: CONTROL GROUP

I, ____ , have been fully informed about the nature of this research and hereby give my consent to act as a participant for the research. I also give consent for all data collected to be made available for research purposes.

Testing procedure:

The testing procedure consists of two parts:

1. Answering a questionnaire based on their training load and availability to train as well as help the study to understand whether participants have free time, and/or the finances to do strength training at home or at the gym.
2. Record performance data during test sessions after participating in regulation ball training (control group).

Risks to participants:

The risks associated with the involvement as a participant in this study would be no different to cricket bowling in a normal net practice or match situation. If any adverse effects do occur, participants will be referred to a medical doctor.

Benefits to participants:

Participants will not be paid for their participation in the study trial but will be able to keep possession of cricket balls given to them to be used during the study trial. Participants will also be able to use the study trial as extra bowling practice. In addition, all results will be distributed in a simple written report and participants will be allowed to ask questions and can receive feedback upon request.

Privacy:

I understand that my anonymity is ensured in any publication of data and will be coded for analysis to enhance my safety and confidentiality and that all data generated from the study trial will be stored and analysed in a manner that maintains my confidentiality. I am aware that I have the right to withdraw from the study trial at any stage without stating a reason and without prejudice.

Participant:______________________________Signature:____________________Date:______________

Researcher:______________________________Signature:____________________Date:______________

APPENDIX B

Questionnaire

Data collection sheet

QUESTIONNAIRE

Demographic details:

Age: .... Cricket club: ....

Level/team: ....

Are you a student?

☐ No ☐ Full time ☐ Part time

Are you employed?

☐ No ☐ Full time ☐ Part time

Please answer the questions below.

1. Are you currently injured, or have you been injured in the last one month?

   ☐ No ☐ Currently ☐ The last one month

   If so, what kind of injury is/was it? ....

   ....

2. How long have you been playing club level cricket for? .... (years/months)

3. How many hours per week do you participate in club level cricket? ....

4. How many days per week do you participate in club level cricket? ....

5. Do you participate in any kind of resistance training during the cricket season?

   ☐ Yes ☐ No

   If no, why not? ....

   ....

   ....

   ....

   ....

   If yes, how many hours per week and where do you train? ....

   ....

6. Rate how important you think strength and power training is for cricket bowling?

☐ Very important ☐ Important ☐ Neutral ☐ Less important ☐ Not important

7. Have you done any training to increase your bowling velocity?

☐ Yes ☐ No

If yes, what kind of training was it? ....

....

....

8. Do you know your maximum bowling velocity?

☐ Yes ☐ No

If yes, how much is it? ....

When last did you measure it? ....

9. Do you have a gym membership?

☐ Yes ☐ No

If no, why not?

....

....

....

If yes, how many hours per week do you attend gym?

....

10. How many years of bowling experience do you have? ……………………………………………………………

11. How many years of resistance training experience do you have? ………………………………………………

DATA COLLECTION SHEET

Name: .... Stature: ....

Club: .... Mass: ....

Warm up for bowling until players are ready to start test. All balls are to be bowled at full speed.

	First ball	Second ball	Third ball	Forth ball	Fifth ball	Sixth ball	AVERAGE
CODE/FILE NAME							
VELOCITY							
ACCURACY							

Maximum 3 warm up tries for Upper Body Power test.
(4 meter dotted mark off)

	First try	Second try	Third try	BEST
UPPER BODY POWER (SEATED MEDIBALL TOSS)				

Maximum 3 warm up tries for leg power test.
(Distance between reach and board is 20cm)

	First try	Second try	Third try	BEST
REACH				
JUMP				

APPENDIX C

4 week resistance training programme

4 WEEK RESISTANCE TRAINING PROGRAMME

Weeks 1-2:

- Bodyweight squat (2 sets of 10 repetitions)

  Participant started with their hands on their head with feet shoulder-width apart and toes turned slightly out. Participant bent down slowly as if sitting onto a chair. Participant was required to keep the back flat and arms above their head as they descended. The aim was to get the hips lower than the knees. Return to the start position and repeat (Figure 13).

Figure 13: Bodyweight squat

- Bodyweight split squat (2 sets of 6 repetitions each side)

  Participant started with a split stance. He lowers his hips straight to the floor. Return to the start position and repeat (Figure 14).

Figure 14: Bodyweight split squat

- Bilateral hip raise (2 sets of 10 repetitions)

  Participant started by lying flat on his back with knees bent 90 degrees. He raised his hips until the thigh and torso were in alignment. Return to the start position and repeat (Figure 15).

Figure 15: Bilateral hip raise

- Chest pass (2 sets of 6 repetitions with a 3kg medicine ball)

  Participant stood with his feet shoulder-width apart and held the medicine ball with both hands in front of his chest. Forcefully, he passed the ball by pushing it away from his chest. Repeat. (Figure 16)

Figure 16: Chest pass with 3kg medicine ball

- Recoiled overhead slams (2 sets of 6 repetitions with a 3kg medicine ball)
  Participant stood with his feet hip-width apart and a medicine ball held with both hands at chest level. Tightening his abs, he wound the medicine ball up and around his head then brought it forward over his head. He slammed the ball into the ground directly in front of him as hard as he could (Figure 17).

Figure 17: Recoiled overhead slams with 3kg medicine ball

- Standing side toss (2 sets of 6 repetitions with a 3kg medicine ball)
  Participant stood near a wall. He held the medicine ball at chest level and tossed it sideways against the wall (Figure 18).

Figure 18: Standing side toss with 3kg medicine ball

- Recoiled rotational throws (2 sets of 6 repetitions with a 3kg medicine ball)
  Participant stood facing a wall with his landing foot in front of the following foot. He held the medicine ball at chest level with both hands, rotated his body away from the wall then immediately rotated toward the wall and threw the ball as forcefully as possible (with one hand) against the wall (Figure 19).

Figure 19: Recoiled rotational throws with 3kg medicine ball

<u>Weeks 3-4:</u>

- Bodyweight squat (2 sets of 12 repetitions)
  Participant started with his hands on his head with feet shoulder width apart and toes turned slightly out. Participant bent down slowly as if sitting onto a chair. Participant was required to keep his back flat and arms above his head as he descended. The aim was to get the hips lower than the knees. Return to the start position and repeat.

- Bodyweight split squat (2 sets of 8 repetitions each side)
  Participant started with a split stance. He lowered his hips straight to the floor, returned to the start position and repeated.

- Bilateral hip raise (2 sets of 12 repetitions)
  Participant started by lying flat on his back with knees bent 90 degrees. He raised his hips until the thigh and torso were in alignment. Return to the start position and repeat.

- Chest pass (2 sets of 8 repetitions with a 3kg medicine ball)
  Participant stood with his feet shoulder-width apart and held the medicine ball with both hands in front of his chest. Forcefully, he passed the ball by pushing it away from his chest. Repeat.

- Recoiled overhead slams (2 sets of 6 repetitions with a 3kg medicine ball)
  Participant stood with his feet hip-width apart and a medicine ball held with both hands at chest level. Tightening his abs, he wound the medicine ball up and around his head then brought it forward over his head. He slammed the ball into the ground directly in front of him as hard as he could.

- Hop back and throw (2 sets of 8 repetitions with a 3kg medicine ball)
  Participant stood facing a wall with his landing foot in front of his following foot. He held the medicine ball with both hands against his chest, hopped backward then threw the ball with his bowling arm while landing on his landing foot (Figure 20).

Figure 20: Hop back and throw with 3kg medicine ball

- Step behind and throw (2 sets of 8 repetitions with a 3kg medicine ball)

  Participant stood facing a wall with his landing foot in front of his following foot. He held the medicine ball with both hands against his chest, brought his following foot behind his landing foot then immediately stepped forward with his landing foot and threw the ball with his bowling arm (Figure 21).

Figure 21: Step behind and throw with 3kg medicine ball