THE ROLE OF ROTATIONAL POWER AND MOBILITY ON THROWING VELOCITY

Kaushik Talukdar

A thesis submitted to
Auckland University of Technology in fulfillment of the requirements for the degree of Master of Sport and Exercise (MSp&Ex)

2014

School of Sport and Recreation

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extend has been submitted for the award of any degree or diploma of a university or other institution of higher learning.

Signed………………………

Date…………………………

CO-AUTHORED WORKS

The following three manuscripts have been submitted or in preparation for submission for peer reviewed journal publication as a result of the work presented in this thesis.

Talukdar, K., Cronin, J., and Zois, J. (2014). A systematic review of rotational power and mobility assessments. *(Target journal – Strength and Conditioning Journal)*

Talukdar, K., (80%), Cronin, J., (15%), & Zois, J., (5%)

Talukdar, K., Cronin, J., Zois, J., and Sharp, A. P. (2014). The reliability of the rotational power assessment of the core. (*Submitted- Journal of Athletic Enhancement)*

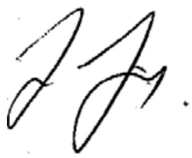
Talukdar, K., (80%), Cronin, J., (10%), Zois, J., (5%), & Sharp, J., (5%)

Talukdar, K., Cronin, J., Zois, J., and Sharp, A. P. (2014). The role of rotational power and mobility on throwing velocity. *(Target journal – Journal of Strength and Conditioning Research)*

Talukdar, K., (80%), Cronin, J., (10%), Zois, J., (5%), & Sharp, A., (5%)

John Cronin

James Zois



Anthony P Sharp

ACKNOWLEDGEMENTS

Firstly I would like to thank my primary supervisor Professor John Cronin. You have been a great influence in guiding and challenging me to think, analyze, review and reflect upon my work. Your honest and sincere advice in shaping my career as a researcher and a strength and conditioning specialist has been invaluable. Your attitude towards life and work has been truly inspiring and I am grateful to have a mentor of your calibre.

I would like to thank my parents Dipankar Talukdar and Shaswati Talukdar for supporting me throughout my life in chasing my dreams. Both of you have given me unconditional love which I will forever be in debt. Your life values have had a strong impact in my life. It is because of your sacrifice and hard work I could travel all the way to New Zealand and pursue a career of my interest. Thank you Maa and Deuta. Kaustav Talukdar (my younger brother), thank you for all the wonderful memories on the sports field, the debates related to cricket and all the beautiful moments we have shared throughout our childhood. My fiancé Neeti Singh Nanda who is the closest friend I have. Thank you for believing in me, standing by me for the last four years and providing the much-needed positive reinforcements in life. I would also like to thank you for helping me with data entry.

I want to express my gratitude to my secondary supervisor Dr. James Zois for providing constructive feedback regarding the technical aspects of writing. Anthony Sharp (Auckland Aces Strength and Conditioning Coach), thank you for your friendship, guidance and help throughout this thesis. Last but not least I would like to thank all the

participants (Aces and Under-19 players), without whom this study would not have been possible.

INTELLECTUAL PROPERTY RIGHTS

ETHICS APPROVAL

The Auckland University of Technology Ethics Committee (AUTEC) granted ethical approval for this research. Ethics Application number: 13/110: Date of approval 17 June 2013.

LIST OF ABBREVIATIONS

CCC	Concordance correlation coefficient
CM	Change in mean
CV	Coefficient of variation
ER	External rotation
FS-MBT	Fast side medicine ball throw
ICC	Intraclass correlation coefficients
IR	Internal rotation
J	Joule
N	Newton
RM	Repetition maximum
ROM	Range of motion
SD	Standard deviation
SEM	Standard error of measurement
SMBT	Side medicine ball throw
W	Watt

ABSTRACT

The ability of players to consistently throw at high velocity with accuracy is considered to be a fundamental task influencing game outcomes in sports such as baseball and cricket. Throwing requires rotational power and mobility of the upper/lower limbs (in the transverse plane) for optimal execution. A clearer understanding of this kinetic chain promises to elucidate athlete's deficiencies and guide future practitioner programming. A screening assessment battery that can diagnose strengths and weaknesses in this kinetic chain is of paramount importance. Therefore the initial objective of this thesis was to explore and review rotational power and mobility assessments such as medicine ball throw, chop and lift, seated hip and thoracic rotation range of motion (ROM). From the literature review it was surmised that these assessments were of great utility and for the most part considered reliable, though it was acknowledged that there was a paucity of research investigating the chop and lift, and no research had quantified both relative and absolute consistency between days in professional athletes. Furthermore, the influence of rotational power and mobility on functional performance was largely unexplored. These two findings provided the focus of the experimental chapters of this thesis.

Following the review of literature, the interday reliability of chop and lift among professional cricketers was investigated. The absolute and relative consistency of the assessment using loads of 15% (chop) and 12% (lift) bodyweight were quantified. The lift (CV: 7.4%-16.3%, ICC: 0.74-0.94) was found to be more reliable between days compared to the chop (CV: 9.2%-19%, ICC: 0.54-0.83). It was suggested that further research on the chop assessment be undertaken given the limitations identified in this study.

The aim of the final part of this thesis was to determine the influence of rotational mobility and power variables such as hip and thoracic rotation ROM, side medicine ball throw (seated and standing), seated cricket ball throw, chop and lift on cricket ball throwing velocity. The seated cricket ball throw was found to be significantly different (12.3%) between fast and slow throwers. Additionally, it was found that bilateral thoracic rotation ROM; hip external rotation ROM on the dominant side, force and work required in the chop was significantly different between fast and slow throwers. Faster throwers in this study displayed greater force (18.4%) and work (31.2%) outputs in the chop compared to slower throwers, however slower throwers showed significantly greater ROM in the thoracic (13.4% to 16.8%) and hip region (11.8%). Substantial (not significant) anthropometrical (height and mass) differences between the groups can be attributed to the differences observed in force and work outputs in chop and seated cricket ball throwing velocity.

In conclusion, greater ROM at proximal regions such as hips and thoracic may not increase throwing velocity in cricket as reduced ROM at proximal regions can be useful in transferring the momentum from the lower extremity in an explosive task such as throwing. Future research should investigate both proximal and distal region contribution and thereafter assess the influence on cricket ball throwing velocity.

CHAPTER 1

INTRODUCTION

My brother and I became interested in cricket at a very early age. Since then we progressed from competing against each other in our backyard to playing state level age group cricket. In the early stages of my competitive career I struggled due to the lack of available knowledge with regards to physical preparation for the sport. I have always believed that the physical and physiological requirements of cricket are much more complex than many think. Therefore I embarked on my journey in learning the art and science of physically preparing the cricket player both on the field and academically. Over the years I have had the opportunity of working with various cricketers from age group to professional level. This thesis is a continuation of my academic growth.

As my understanding in exercise and sports science grew, I realized most sports are very similar in nature i.e. the requirements of some of the kinematic and kinetic determinants of movement are similar, irrespective of the sport. One observation was that most force-velocity-power assessments are often linear in nature (Strockbugger & Haennel, 2001) but most sports involve some amount of non-linear activity. Hence sports that involve striking and throwing would seemingly require different assessments to the more conventional approaches utilized by most practitioners. Due to the role of rotation in many sports, including cricket, assessing both proximal and distal segments in a transverse plane would seem logical and should provide valuable information with regard to strength, power and mobility among rotational athletes.

There are currently no published studies involving rotational power and mobility assessment among cricketers and therefore one of the primary objectives of this thesis is to bridge the gap between scientific findings and practical applications in designing a rotational assessment battery for professional and age group level cricketers. Four movements are advocated that could diagnose strengths and weakness and thereafter inform strength and conditioning programming: side medicine ball throw (seated and standing), chop and lift, seated bilateral thoracic rotation and seated active hip internal and external rotation. Therefore an assessment battery involving both rotational power and mobility could provide valuable information regarding throwing velocity in cricket. For example, it may be that greater rotational range of motion (ROM) at the hip and in the thoracic region, in combination with greater rotational power, would result in increased throwing velocity. However, whether such a contention is true needs investigation and, as such, this problem provides the focus of this thesis.

Purpose statement

The purpose of this thesis is to quantify interday reliability of a rotational power assessment of the core and thereafter assess the influence of rotational power and mobility on throwing velocity. With the paucity of research available on the influence of rotational mobility and power on throwing velocity, it is critical to understand the influence of these variables in order to provide practical information regarding the assessment and development of the throwing athlete.

Study aims

The aims of this research were as follows:

1. To review the published literature on the utility, reliability and relationship to performance and injuries of rotational mobility (active hip and thoracic rotation ROM) and rotational power (medicine ball throws and chop and lift).
2. To quantify the interday reliability of a rotational power assessment of the chop and lift among professional athletes using a linear position transducer.
3. To determine the role of rotational mobility (active hip and thoracic range of motion) and rotational power (side medicine ball throw and chop and lift) on throwing velocity in cricket.

Study limitations

1. The relationship to performance section in Chapter 2 (literature review) for chop and lift and thoracic rotation ROM is limited due to the paucity of research available.
2. The results from this research may not be generalized to other rotational-based sports due to the specificity of throwing action involved in cricket.
3. There can be end range deceleration encountered during the chop and lift assessment performed on a cable pulley that can influence the power values in Chapter 3 (The reliability of a rotational power assessment of the core) and Chapter 4 (The role of rotational power and mobility on throwing velocity).
4. Non- significant intergroup means, standard deviations and differences are only provided for the player’s dominant side in the results section (Chapter 4).
5. The weight of the medicine ball (19.6N) and the percentage of bodyweight (15% and 12%) for chop and lift respectively were similar for both professionals and under 19 players in this study.

Study delimitations

1. This study did not include participants with a history of musculoskeletal injuries within the last three months prior to testing.
2. All participants in this research were male cricketers from Auckland Cricket Association (ACA) between the ages of 17 to 27 years.
3. With regards to hip and thoracic ROM, it is acknowledged that mobility and ROM are not synonymous and mobility is influenced by a number of mechanical and neurological factors. The measures used in this study (i.e. ROM) explain some of the variance associated with mobility and therefore the term mobility is used in this context.
4. The chop and lift are considered as rotational power movements in this study as the rotation occurs in the upper region of the spine as oppose to lower region.

Thesis format

This thesis is presented as a series of chapters, which after this chapter includes a combination of original research and reviews. It should be noted that because this thesis is presented as a series of chapters, of which chapters 2, 3 and 4 are standalone publications, there might be some repetition.

The second chapter is a systematic review of utility, reliability and relationship to performance and injuries of current practices involved in rotational mobility and power assessment. This chapter informed the assessments to be used in the ensuing chapters and will be submitted to the *Strength and Conditioning Journal*. From the literature review, it became apparent that there was not a great deal of information on one of the tests chosen for the assessment battery – the chop and lift. The third chapter therefore quantifies the reliability of the chop and lift using professional male cricket players. This chapter has been submitted to the *Journal of Athletic Enhancement*. The third chapter is the culmination of the prior literature review and experimentation, a cross sectional study determining the role of rotational power and mobility on throwing velocity. This chapter will be submitted to the *Journal of Strength and Conditioning Research*. The last and final chapter provides a brief summary of the findings, practical applications relevant to strength and conditioning practitioners and suggests future research directions.

CHAPTER 2

A SYSTEMATIC REVIEW OF ROTATIONAL POWER AND MOBILITY ASSESSMENTS

Introduction

The ability to throw at high velocity with accuracy is important for successful performance in baseball and cricket (Cook & Strike, 2000). Overhead throwing is a movement that occurs in three dimensions (Tillar & Etema, 2009), therefore rotational power and mobility can play an integral role in enhancing overhead throws in cricket and other overhead throwing sport. A lack of optimal rotational power and mobility in the kinetic chain could affect throwing velocity due to the sequence of proximal to distal linkage (Putnam, 1993). The training interventions that have been commonly employed for throwing sports to increase throwing velocity and athletic performance are general (to increase the overall maximal strength and contractile abilities), special (to increase ballistic power output using tools such as medicine balls and cable pulleys) and specific resistance training (such as weighted balls) (DeRenne, Ho, & Murphy, 2001). The goal of the above training interventions is to enhance force production and increase speed of movement (Freeston & Rooney, 2008; DeRenee & Szymanski, 2009). However, currently no studies have reported the association between some of the special strength interventions tools such as medicine ball and cable pulley or mobility (such as hips and thoracic) in a transverse plane with cricket ball throwing velocity.

A screening tool that identifies rotational mobility and power in the transverse plane would be of diagnostic value to the practitioner. The purpose of this review is to identify the utility and reliability of current rotational power and mobility exercises used by practitioners. In addition, the relationship of these exercises to functional tasks and injuries involved in sports will be discussed.

Rotational Power: Medicine ball

Medicine ball assessment is a popular mode of assessing power in rotational reliant sports (Earp & Kraemer, 2010). Rotational power assessed via medicine ball throws is highly sport-specific as the exercise closely mimics the range of motion and velocity encountered in sports (Stodden, Campbell, & Moyer, 2008). The following section will provide a brief description on medicine ball throws, emphasizing the side medicine ball throw, its utility, reliability and relationship to performance.

Studies have identified the various medicine ball throwing techniques (scoop, squat and overhead) (Kohmura, Aoki, Yoshigi, Sakuraba, & Yanagiya, 2008; Rivilla- Garcia, Martinez, Grande, Sampedro- Molinuevo, 2011; Lehman, Drinkwater, & Behm, 2013), however, less is known about the side medicine ball throw. The side medicine ball throw is incorporated into training programs to develop trunk rotator muscle strength and power, particularly in rotational sports but there has not been much information regarding the throwing technique or ideal weight to use in training and assessments as it relates to physical ability of the participants (Ikeda, Kijima, Kawabata, Fuchimoto, & Ito, 2007). A side medicine ball throw is performed by grasping the medicine ball with both hands, rotating the trunk opposite to the throwing direction as in a countermovement (see Figure 1a), followed by rotating the trunk to the throwing direction (see Figure 1b), attempting to throw the medicine ball as far and/or as fast as possible (Ikeda et al., 2007).

Figure 1a: Side medicine ball start

Figure 1b: Side medicine ball finish

Utility

In a rotational activity like throwing, the athlete positions their body so that the greatest angular velocity is transferred to a ball directly while maintaining a high degree of precision (Akutagawa & Kojima, 2005). It has been postulated that medicine ball training-patterns similar to the sporting event could be beneficial to baseball players and other rotational power athletes (Szymanski, Szymanski, Bradford, Schade, & Pascoe, 2007). Currently there are only two studies that have investigated the side medicine ball throw. Ikeda et al. (2007) investigated the correlation between side medicine ball throw and physical ability (1RM parallel squat, 1RM bench press, isometric maximum trunk rotation torque, bench press peak power, static squat jump peak power and vertical jump height) among both male and female population. In addition, Ikeda, Miyatsuji, Kawabata, Fuchimoto and Ito (2009) investigated trunk activity in the side medicine ball throw among male athletic population. These studies (Ikeda et al., 2007; 2009) incorporated two-side medicine ball throwing techniques: side medicine ball throw (S-MBT) and fast side medicine ball throw (FS-MBT). The SMBT emphasized throwing as far as possible (maximum distance) and the FS-MBT emphasized horizontal trunk rotation to throw as fast as possible (maximum velocity).

Ikeda et al. (2007) used 2, 4 and 6 kg medicine balls, and reported the mean distance and velocity for the SMBT and FSMBT ranging from 8.9±1.7m to 15.4±2.1m (males), 6.2±0.4 to 11±1(females) and 5.85±0.48m/s to 8.12±0.64m/s (females), 6.89± 0.76m/s to 10.08±0.87m/s (males) respectively. In comparison, the participants in Ikeda et al.'s (2009) study produced higher mean velocity in FSMBT (7.10±0.28 to 11.49± 0.68m/s) compared to (Ikeda et al., 2007) using similar medicine ball loads. Potential explanation for these differences is that Ikeda et al.'s (2009) study included athletic participants who spent a considerable amount of time in rotational activities such as throwing and therefore could have higher rotational strength and power compared to the non-athletic counterparts in (Ikeda et al., 2007) study.

Reliability

Researchers have found the medicine ball throw (scoop, side and overhead) over a variety of loads (2 to 6 kg) to be reliable in athletic, non–athletic, male and female population (ICC≥0.84) (Table 1). In addition, all the studies reported between trial reliability and no study quantified between day reliability of the assessments. Furthermore, only one study Rivilla- Garcia et al. (2011) reported the coefficient of variation (CV %) between trials (3.5% to 6.3%). No other study reported any other measure of absolute consistency e.g. standard error of measurement or typical error. It would seem there is a need for more research in this area that quantifies the test-retest reliability of the medicine ball throw that uses measures of absolute and relative consistency.

Table 1: Reliability of medicine ball throw and relationship to performance

Author	Participants	Performance indicators and measured variables	Reliability	Correlation to performance
Ikeda et al. (2007)	16 males and 10 females, mean age male 18.9±0.6, female 19.1± 0.6 years	Side medicine ball throw distance	ICC=0.96-0.99	Isometric trunk rotation torque right and left, one repetition max parallel squat (males)
		2kg		r=0.47 and 0.61, r=0.68
		4kg		r=0.60 and 0.64, r=0.72
		6kg		r=0.74 and 0.66, r=0.73
		Fast side medicine ball velocity	ICC=0.89-0.95	Isometric trunk rotation torque right and left, one repetition max bench press and parallel squat (males)
		2kg		r=0.63 and 0.62, 0.62, and 0.72
		4kg		r=0.66 and 0.61, 0.60, and 0.68
		6kg		r=0.69 and 0.64, 0.66, and 0.71
Ikeda et al. (2009)	15 male competitive throwers & 15 male competitive baseball players, mean age 19.4±0.9 years	Fast side medicine ball velocity	ICC=0.89-0.97	Isometric trunk rotation torque right and left
		2kg		r=0.52 and 0.60
		4kg		r=0.66 and 0.83
		6kg		r=0.47 and 0.74
Kohmura et al. (2008)	43 college baseball players (7 catchers, 23 infielders, 13 outfielders) mean age 20.17±1.4 years	Medicine ball scoop 4kg	ICC=0.84	Fielding r=0.27 Batting r=0.68
Lehman et al. (2013)	42 college level baseball players, mean age 19.8 ±1.2 years	Medicine ball scoop throw (2.7kg) Lateral to medial jump (right side)		Shuffle baseball right hand throw (allowed to build momentum) r=0.58

Rivilla- Garcia et al. (2011)	94 handball players (senior n=43, under 18 n=51, mean age 23.16 ±5.1years	Overhead heavy (3kg) medicine ball throw distance	ICC=0.99, CV=3.5%	Handball throwing velocity r=0.78
		Overhead light (0.8kg) medicine ball throw distance	ICC=0.99, CV=6.3%	Handball throwing velocity r=0.90

ICC- intraclass correlation coefficients
CV- coefficient of variation
r- correlation

Relationship to performance and limitations

The relationship between the medicine ball throw and sporting performance can be observed in Table 1, the highest correlation noted between a light medicine ball (0.8 kg) and handball throwing velocity. Evidence from the current literature suggests prevalence to load-specificity; heavier medicine balls elicit weaker correlations to throwing tasks. With regards to other sporting performance, Kohmura et al. (2008) reported that the scoop medicine ball throw had very little shared variance with fielding evaluation (throwing distance, standing long lump, agility T test and scoop medicine ball throw, were analysed together as part of evaluation) (~7%) compared with batting (~46%). The stronger correlation with batting may be attributed to the influence of rotational muscular strength/power on bat swinging speed/ball-hitting velocity (Kohmura et al., 2008).

Muscular power measured via the side medicine ball throw and isometric rotation torque (Ikeda et al., 2007) ranged from 0.47 to 0.74 in males, stronger correlations noted at heavier (6 kg) medicine ball loads (see Table 1). In addition, the relationship between the fast medicine ball throw and isometric rotational torque ranged from 0.47 to 0.83 in males (Ikeda et al., 2007; 2009), however the relationship with load is unclear with this type of medicine ball throwing motion. It would seem that whether the motion is slow or fast the relationship to isometric rotation torque is moderate-to-strong. However, the shared variance (r^2) between measures is on average <50%, suggesting they are mainly measuring different qualities, which intuitively explains the static-dynamic differences of the movement patterns. Stronger correlations might be associated with dynamic measures such as isokinetic or isotonic rotational torque. The study by Nuzzo, McBride, Cormie, and McCaulley (2008) supports this contention as the authors reported higher correlations between dynamic variables such as peak velocity, relative peak power (r=0.826, r= 0.726) and counter movement jump height compared to isometric squat peak force, isometric mid-thigh peak force, squat 1RM, and power clean 1RM (r=-0.073, 0.276, -0.219, and 0.059 respectively).

Rotational Power: Chop and Lift

The chop and lift are multi-planar (three-plane) movements, which require diagonal and spiral motions of the arms, shoulders, trunk, hips and the legs. The exercise can be performed standing, seated or half kneeling (Cook & Fields, 1997). The chop action incorporates a pull action of the upper body followed by a push action (see Figure 2a and b), stabilization of the trunk in three planes and weight transfer for dynamic balance. It requires the spine to resist rotation while the upper body produces motion (rotation and flexion/ extension). The lift incorporates a pull action followed by a push action of the upper body (see Figure 3a and b), stabilization of the trunk in three planes and weight transfer for dynamic balance (Cook & Fields, 1997).

Figure 2a: Chop start

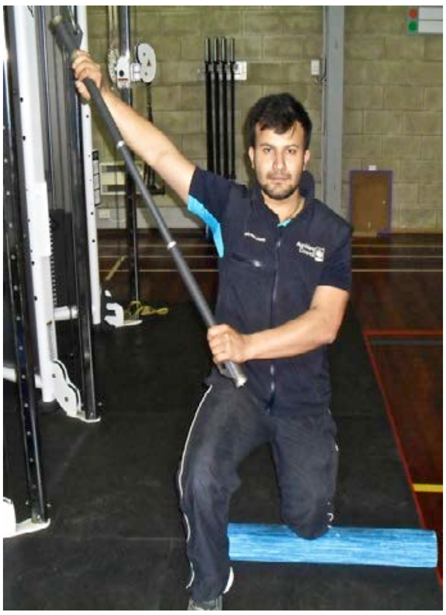


Figure 2b: Chop finish

Figure 3a: Lift start

Figure 3b: Lift finish

A high-low pulley system or cable machine is considered as the most practical piece of equipment to perform the chop and lift assessment. On a high-low cable machine a cable from a low pulley can be pulled up or a cable from a high pulley can be pulled down. A large amount of weight is not needed because a long lever arm exists and many body parts contribute to the movement (Voight, Hoogenboom, & Cook, 2008). Small increments can be adjusted on the cable pulley in order to determine peak strength and power outputs. In a half kneeling cable chop the resistance is pulled down and across the body into the open space created by the half kneeling position, in a spiral and diagonal fashion. The handle bar is pulled to the mid-point of the chest with the lower arm. The angle of pull is maintained throughout the movement along with an erect spine and neutral pelvis with shoulder in line with the hip. The half kneeling lift is the reverse of the half kneeling chop. The handle bar is pulled up to the center of the chest with the palms down, beginning with the outside arm and then finishing with a press of the inside arm (Voight et al., 2008).

Utility

The chop and lift movement represent distinct spiral and diagonal patterns that mimic functional activities of sport and daily living (Voight et al., 2008). They can reinforce recruitment of core musculature either for mobility or stability. The use of chop and lift assessment has been particularly popular in rehabilitation providers who practice neuro-developmental strategies during treatment of patients whose central nervous system function is compromised (Voight et al., 2008). The chop and lift can also be used to assess discrepancy between left and right side of the trunk musculature while performing a functional task. There has not been many studies investigating strength and power qualities of a chop and lift assessment to date.

Palmer and Uhl (2011) investigated the peak muscular power outputs of chop and lift on an isotonic dynamometer. The primary purpose of the study was to evaluate the interday reliability of peak muscular power output measures using diagonal chop and lift tests among general population (18 healthy adults, 10 men and 8 women). The participants used the tall kneeling stance while performing the chop and lift assessment on a dynamometer (BTE Technologies Primus RS, Inc, Hanover, MD). The weight of the dowel was calculated as part of the test resistance provided by the dynamometer. The initial resistance of the pulley was standardized to approximately 12% and 15% of the individual's body mass for the lift and the chop respectively. Resistance was further increased by 1.35kg for the lift and 2.25kg for the chop after a successful 1RM (repetition max). Inability to produce an equal or greater peak power output (chop: 346 - 395 W and lift: 181-223W) from the previous test trial resulted in reduction in resistance by 0.45 kg for the lift and by 1.35 kg for the chop until maximum peak power was achieved.

A cable pulley system has been a very popular method in training and assessing multi-planar high velocity strength and power qualities in sports due to the advantage of adding external resistance. Andre et al. (2012) investigated rotational power in a seated position using loads of 9, 12, and 15% bodyweight among healthy college students (8 men, 15 women). The authors incorporated a cable pulley system with an external dynamometer (Fitrodyne; Fitronics, Bratislava, Slovakia) to measure rotation power. The assessment protocol used in the study was not similar to a chop and lift assessment as the participants were required to perform a 180 degrees trunk rotation in a seated position with the elbows fully extended. Andre et al. (2012) reported a mean peak power range from 20.1±7.2W to 33.5±13W. In comparison, Palmer and Uhl (2011) study reported a higher mean peak power output in the chop and lift assessment (mean 373± 44W) for the chop and (mean 216±34W) for the lift. A possible explanation for the difference in peak power outputs between both the studies could be due to the fact that there is a high contribution of the distal segments (arms) in a chop and lift compared to a seated trunk rotation where the moment arm is longer and hence lower power output is achieved.

Reliability

Palmer and Uhl (2011) reported that the cable pulley system was effective and reliable in assessing rotational power. This study incorporated the chop and lift technique in a tall kneeling position, performing diagonal chopping and lifting patterns with an erect and upright torso. The researchers reported high ICCs: 0.87-0.98 and 0.83-0.96 and low standard error of measurement (SEM: 28-34 chop and 41-52 lift) using 12% and 15% of bodyweight for the lift and the chop respectively. The tests were performed on three different days separated by at least one week.

Andre et al. (2012) also reported high ICCs: 0.97, 0.94 and 0.95 using 9%, 12% and15% of bodyweight respectively. The tests were performed on 3 different days separated by 1 week. However, the difference in positions between the studies while executing the respective assessments should be noted, as the seated position (Andre et al., 2012) lacks the kinetic linkage of proximal to distal, and moreover, does not allow an erect and stable torso while performing 180° seated torso rotations. Furthermore, Andre et al.'s (2012) study did not report any measures of absolute consistency such as CV or SEM and relied on unpublished data reporting CV and SEM of previous studies.

Relationship to performance and limitations

There is currently no published research that has investigated chop and lift, as well as throwing velocity. However, Palmer (2012) completed a PhD dissertation reporting moderate to strong correlation between peak and mean throwing velocity/Kg of bodyweight with the chop (r=0.69, r=0.64, p=. 001) and lift (r=0.73, r= 0.58, p=. 001) power outputs/kg of bodyweight in 46 healthy (17 female collegiate softball and 29 male collegiate baseball players).

Rotational Mobility: Hip

Lack of flexibility in athletes has been related to both a decrease in performance and an increase in muscular injuries (Shellock & Prentice, 1985). Of interest in this section is the flexibility of the hip during internal and external rotation. Hip rotation range of motion (ROM) can be assessed in a seated position, with the legs resting comfortably off the edge of a standard treatment table and the hands resting flat on the table for stabilization of the trunk or around the hips (see Figure 4a and b). The femur should be stabilized to limit accessory motion, while the lower shank is rotated (internally and externally) until end ROM (Launder, Moore, Sipes, & Meister, 2010). A digital inclinometer can be used to measure the hip rotation, as it can provide 360° information with respect to either a vertical or horizontal reference and is accurate up to 0.1° (Launder et al., 2010).

Figure 4a: Hip internal rotation

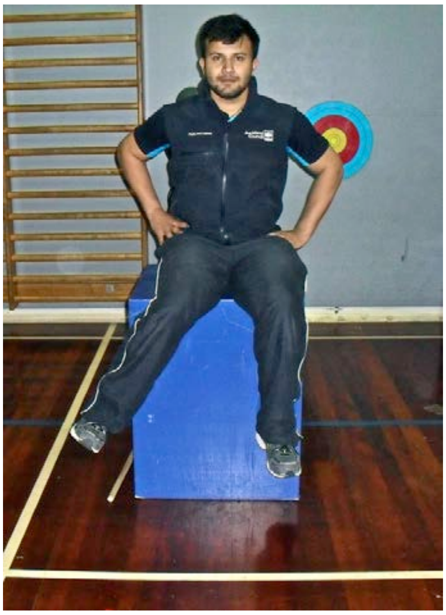
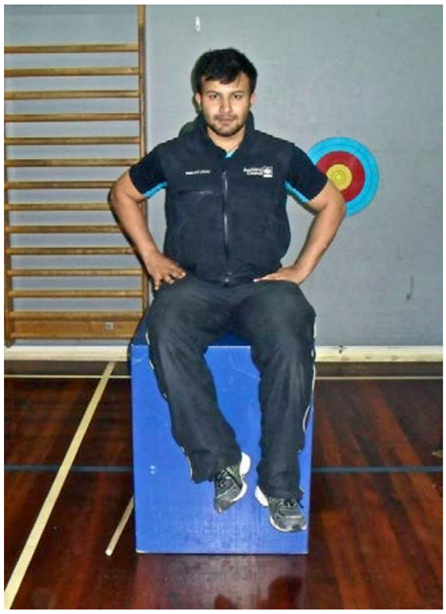


Figure 4b: Hip external rotation



Utility

A number of researchers have used the seated and prone lying hip rotation test to assess ROM in athletes–non-athletes, males–females, young–old and the injured–non-injured (see Table 2). Ranges of motion for internal rotation (IR-range 22± 8.9° to 50.8±9.2) was marginally greater than the range in motion for external rotation (ER-range 29.8± 8.8 to 44.6±13.4°). The sample that had the greatest IR and ER were female professional golfers (Gulgin & Armstrong, 2008) and male professional baseball players (Robb, Flesig, Wilk, Macrina, Bolt, & Pajaczkowski, 2010) and the least IR and ER were male professional baseball players (Ellenbecker, Ellenbecker, Roetert, Silva, Keuter, & Sperling, 2007) and patients' with low back pain (Ellison, Rose, & Sahrmann, 1990) respectively. In addition, female tennis players had significantly greater IR on the dominant and non-dominant sides whereas male tennis players had higher ER on the dominant and non-dominant sides compared to their female counterparts (Ellenbecker et al., 2007). The difference in IR and ER ROM between populations can be observed in Table 2 i.e. athletic (Ellenbecker et al., 2007) non-athletic (Kouyoumdjian Coulomb, Sanchez, & Asencio, 2012) athletic/non-athletic patients with low back pain (Gulgi & Armstrong, 2008; Ellison et al., 1990 respectively) and patients with hip dysfunction (Pua, Wrigley, Cowan, & Bennell, 2008). The hip rotation ROM techniques (seated and prone) are useful due to their versatility in assessing wide range of population therefore making them ideal assessment tools in diagnosing hip rotation ROM. Inadequate ROM and excessive asymmetry in hip rotation may cause spine and lower extremity dysfunctions (Sahrmann, 2002) that can negatively affect performance. Therefore assessing hip rotational mobility can be useful in designing training programs for rotational athletes.

Table 2: Hip internal/external range of motion and reliability

Authors	Participants	Hip Internal/External ROM	Method/Reliability/Correlation
Ellenbecker et al. (2007)	64 and 83 male and female elite tennis players 101 male Professional baseball players	IR dominant and non- dominant (male and female)- 27°, 26°, 37° and 35°. ER dominant and non-dominant (male and female)-37°, 36°, 36° and 35°. IR/ER both sides-23°, 22°, 35°and 34°	Active prone lying, Neutral hip alignment and 90° knee flexion ICC = 0.99
Ellison et al. (1990)	Group 1 – healthy (25 male, 75 women). Group 2 – 50 patients with lower back pain (21 male 29 female)	Left IR and ER-38.1°and 35.8°; right IR and ER-38.2° and 35.4° Left IR and ER-31.7°and 36.5°; right IR and ER-32.7°and 36.9°	Prone lying inter-rater: Healthy- left and right IR and ER – ICC = 0.96 to 0.99. Left and right IR and ER – ICC = 0.95 to 0.97,
Gulgin & Armstrong (2008)	31 LPGA Golfers	Low back pain IR and ER left and right- 49.6°, 43.7°, 47.2° and 44.6°. No pain-48.8°, 39.6°, 49° and 39.7°	Prone lying passive. ICC IR and ER right and left- 0.98, 0.96, 0.91 and 0.97
Kouyoumdjian et al. (2012)	120 adults (71 women, 49 men) between 20 and 60 years old	Position1 (dorsal decubitus) IR and ER rotation- 29.6° and 38.5°; Position 2 (ventral decubitus)- 35.3°and 41.8°; Position 3 (seated)- 37.9°and 40.7°	IR (CCC) ER (CCC) 0.80 0.67 0.83 0.66 0.77 0.69

Pua et al. (2008)	10 men, 12 women with hip osteoarthritis	Test retest hip IR and ER 30.6°, 30.2°, 42.8°, and 43.1°	Passive seated hip and knee in flexion at 90°. ICC: hip internal rotation – 0.93, CV- 12.7% & hip external rotation- 0.96, CV – 8.3%
Robb et al. (2010)	19 professional baseball players	ER and IR rotation dominant- 44° and 50.8°. ER and IR rotation non –dominant -35.6° and 31.3°	Pearson rank correlation coefficient: total arc of non – dominant hip rotation and throwing velocity r=0.50*

IR- internal rotation, ER- external rotation
ICC – intraclass correlation coefficient
CV –coefficient of variation
r= correlation*
CCC- concordance correlation coefficient

Reliability

Researchers have found both passive and lying hip IR and ER assessments to be highly reliable (ICC ≥ 0.91) among athletes, non-athletes and patients as observed in Table 2. Kouyoumdjian et al. (2012) is the only study that reported a lower reliability using a concordance correlation coefficient (CCC ≤ 0.83). A number of factors such as technique (three separate positions: prone, supine, and seated), sample size and statistical procedure (CCC vs. ICC) might explain the lower reliability reported in this study. Furthermore only Pua et al. (2008) study reported coefficients of variation (CV). No other study reported any other measure of absolute consistency e.g. standard error of measurement (SEM) or typical error.

With regards to equipment and protocols Pua et al. (2008) and Ellison et al. (1990) utilized inclinometers to measure the hip IR and ER, whereas Gulgin and Armstrong (2008) study advocated a plastic goniometer. Pua et al. (2008) performed the passive hip IR and ER in a seated position unlike Gulgin and Armstrong's (2008) and (Ellison et al.'s (1990) studies that incorporated the prone lying position. Once again irrespective of equipment and posture, the ICCs were found to be very high. To gain a more comprehensive understanding associated with the reliability of these variables, measures of absolute consistency such as CV or SEM are needed. Furthermore, Ellenbecker et al. (2007) was the only study that measured active ROM and reported high reliability using a digital camera.

Relationship to performance and injuries

Researchers have reported lack of hip rotation ROM to be an important factor among athletes suffering from low back pain. Vad, Bhat, Basarai, Gebeh, Aspergren, and Andrews (2004) reported significant difference (30.2%; $p<0.05$) in hip medial rotation (lead leg) between symptomatic (low back pain) and asymptomatic professional golfers. The authors concluded that 14 out of 42 participants reported low back pain also lacked hip internal rotation in their lead leg. Similarly, Gulgin and Armstrong (2008) reported that eight LPGA golfers out of 31 (Ladies Professional Golf Association) had five degrees or more side-to-side variance in their hip internal ROM (seven out of the eight golfers had self-reported low back pain). Additionally, ten LPGA golfers had a five-degree or more side-to-side difference in their hip external ROM (seven out of those self-reported low back pain). Therefore, a reliable and valid measure of hip internal and external rotation ROM could provide pertinent information in assisting identification of golfers with and without low back pain.

There are few studies reporting the relationship between hip rotation ROM and overhead throwing performance. Robb et al. (2010) was the only performance related study known to these researchers that reported correlation between limited total arc of hip rotation (internal and external) in the non-dominant leg and ball velocity (r = 0.50) in 19 male professional baseball pitchers using a fluid filled goniometer. Further investigations are required to establish the association between hip rotation ROM and throwing velocity. Due to the kinetic chain linkage of proximal to distal, it can be useful to assess rotational hip mobility for athletes involved in throwing and striking activities.

Rotational Mobility: Thoracic

Athletes whose sports have a large rotary component (golf, rowing, baseball, and gymnastics) may require assessment that accurately quantifies thoracic range of motion (Johnson, Kim, Yu, Saliba, & Grindstaff, 2012). Assessing thoracic range of motion is a fundamental aspect for both injury-prediction and performance enhancement programs (Hoogenboom, Voight, Cook, & Gill, 2009; Booth, 2005). In this regard, a seated rotation test can be used to give some indication of thoracic mobility. A seated active thoracic rotation assessment utilized by (Johnson et al., 2012) study can be performed placing a stick across the chest and arms crossed over a bar on a high box or table (see Figure 5a and b). Furthermore, a medicine ball can be placed between the knees to minimize lower extremity motion during thoracic rotation (not shown in Figure 5a and b). Johnson et al. (2012) has successfully used a goniometer-aligned parallel to the ground at the midpoint between T1 and T2 spinous processes (thoracic segment of the spine), with the spine of the scapula as a reference point measuring the ROM with the moving arm of the goniometer. The inclusion criteria for this section of the literature review have been limited to non-clinical studies based on reliability of various thoracic rotational techniques.

Figures 5a: Thoracic rotation Start

Figure 5b: Thoracic rotation finish

Utility

Thoracic rotation could play an integral role in any rotational activity (Sahrmann, 2002). The range of motion in the thoracic segment is particularly important for the lower segment of the spine (lumbar) (Sahrmann, 2002). The vertical orientation in the transverse plane and the 45° angle orientation in the frontal plane of the facet joints are the reasons for limited rotational range in the lumbar spine. Therefore it is believed that "the thoracic spine, not the lumbar spine, should be the site of the greatest amount of rotation of the trunk" (Sahrmann, 2002, p. 62).

A mean thoracic rotation of 55.4±9.2° has been reported when using the seated rotation test with the bar in front amongst 15 men and 31 women (Johnson et al., 2012). Authors also assessed thoracic rotation range of motion utilizing other positions such as seated rotation with bar in back (41.6±8.7°), half kneeling rotation bar in back (48.2±10.7°) and front (60.6±10.8°) and lumbar-locked (40.8±10.7°) rotation. The possible difference in the range of motion between the positions could be due to the fact that the bar in front position allowed greater shoulder joint to spine rotations (approximately12° to 14° more than the bar in the back position) (Johnson et al., 2012). Additionally, the bar-in-front position variation both in seated and tall kneeling allowed easier anatomical landmarks such as the spine of the scapula to be identified. Furthermore, the seated position in this study could have provided greater stability for those who had difficulty maintaining balance in a half kneeling position. However, the seated positions (bar in front and back) required participants to keep a ball between their knees during the assessment that would have provided greater standardization and restricted rotation to better effect. Therefore the authors reported a higher rotation in the tall kneeling stance with the bar in front.

Reliability

Johnson et al. (2012) reported between day's intra-tester and within day intra-tester ICC values of > 0.80 (for all the positions). Additionally all the techniques had low measurements error with SEMs (standard error of measurement) less than 3° and MDC (minimal detectable change) values <6°.

Heneghan, Hall, Hollands and Balanos (2009) investigated stability and intra-tester reliability of an *in vivo* measurement of thoracic rotation using an innovative methodology. These researchers incorporated ultrasound images along with linear array transducers using a frequency range of 3-11 MHz. The authors minimized the movement of lumbar spine with an adjustable wooden bar positioned at the level of L1 (start of lumbar vertebrae). The spinous process of the C7 (seventh cervical vertebrae) was palpated in neutral position and marked; thereafter an ultrasound image of T1 (first thoracic vertebrae) spinal laminae was acquired in the horizontal plane using reference lines on the monitor. The participants were asked to actively rotate maximally to record the new transducer position. The authors reported high within day intra-tester reliability (0.89-0.98) and moderate to high reliability (0.72-0.94) between days (7-10 days apart) when assessing 24 asymptomatic participants. Heneghan et al. (2009) also reported a high mean composite range of motion of 85.15° across a single trial with SEM –3.04 and CV –17.4%. Due to the high reliability observed in both the above-mentioned studies, a seated thoracic rotation ROM assessment can be successfully incorporated in accessing bilateral (both sides) thoracic rotational mobility.

Relationship to performance and injuries

Booth (2005) found the seated bilateral thoracic rotation as one of the important assessment tools for evaluating golf swing technique. Thoracic rotation can assist in the whole body turn required in golf, as opposed to moving the trunk during the swing. However, there is no direct evidence of increased thoracic rotation affecting functional performance such as throwing. Myers, Lephart, Tsai, Sell, Smoliga and Jolly (2008) found moderate correlations between upper torso rotational velocity, and torso pelvic separation to maximum ball velocity in a golf swing ($r = 0.59$, and $r = 0.54$ respectively) when assessing 100 recreational golfers.

Bilateral thoracic rotation is also considered an important variable in assessing spine mobility deficits. Activities such as rolling patterns (primitive movement pattern) are widely used in a rehabilitation setting to develop neuromuscular control and coordination of the core and extremities of athletes (Hoogenboom et al., 2009) Patients or clients who perform the rolling test should have sufficient trunk, upper extremity and lower extremity mobility. The seated trunk rotation is designed to identify mobility in the thoracolumbar spine. Hoogenboom et al. (2009) incorporated the seated thoracic rotation test to identify mobility impairments in the rolling pattern. Mobility impairments in the thoracic spine are believed to affect rolling pattern and other whole body rotational activity. Hoogenboom et al. (2009) advocated, that 30° of bilateral thoracic rotation is required for an effective rolling pattern. Therefore investigating bilateral thoracic rotational range of motion among athletes could inform rotational mobility deficits related to sport.

Practical Applications

As suggested previously, the function of rotational power and mobility can play a crucial role in throwing due to the involvement of the trunk and the extremities (upper and lower) in the transverse plane. It is important to develop a rotational screening assessment battery that can diagnose strengths and weaknesses and inform appropriate programming. Four movements: side medicine ball throw, chop and lift, hip internal/external rotation ROM and thoracic rotational ROM are suggested that might be of diagnostic value as a screening tool. However, prior to inclusion of such tests in an assessment battery, an understanding of their utility-ease of administration, reliability and relationship to functional performance is needed. The following are the major findings and recommendations with regards to the tests reviewed.

- Utility: Medicine ball throws can be easily used to effectively assess rotational power and have the added advantage of being ballistic i.e. mitigating end range deceleration. The chop and lift assessments can provide useful information on the rotational power of the trunk due to the requirement of trunk control in all three planes. However, the administration of the assessment can be challenging as it requires equipment such as a cable pulley system, which inherently has limitations due to the non-ballistic motion i.e. end range deceleration. Furthermore, the cable pulley system needs to be instrumented with technologies such as a linear position transducer, which incurs additional cost and expertise. In terms of mobility, hip and thoracic rotation ROM can be incorporated easily into any assessment battery, however, will require strict attention to technique to ensure that supplementary movements from adjacent joint is eliminated.
- Reliability: Medicine ball throws (side, scoop, and overhead) and the chop and lift have been found to be reliable measures of rotational power. However,

research in this area would benefit from more thorough methodological approaches i.e. utilization of athletic populations, single gender analysis, test-retest measures of reliability and identifying measures of relative consistency i.e. CV, SEM, etc. With regards to mobility, the seated thoracic and hip rotation ROM assessments have been reported as reliable between days. Most studies have reported the reliability of passive hip rotation ROM and therefore relative and absolute consistency of active hip rotation ROM needs to be further investigated among athletic population.

- Relationship to Performance: Researchers have reported moderate to strong correlations between medicine ball throws (overhead, scoop and side) and functional and muscular performances. However, the weight of the medicine ball, training age, specificity of the throwing action and gender no doubt affect the magnitude of this relation. In regards to chop and lift, there are currently no published studies reporting their association to performance, therefore further research is necessary to establish the utility of this measure as a predictor of performance. Similarly there is limited research determining the relationship between hip and thoracic rotation ROM, and performance. Most research regarding hip and thoracic ROM has been injury focused. However, limited hip rotational ROM has been reported to influence throwing velocity in baseball. Therefore further investigation is necessary in establishing the influence of hip and thoracic mobility on functional performance such as throwing velocity.

CHAPTER 3

THE RELIABILITY OF A ROTATIONAL POWER ASSESSMENT OF THE CORE

Introduction

Most power measurements incorporate the lower limbs and are often linear in nature (Strockbugger & Haennel, 2001), however less is known about the involvement of the upper extremities and/or the trunk musculature. Though there is a great deal of debate as to what constitutes the core, the core is said to include the spine, hips and pelvis, proximal lower limbs and abdominal structures (Kibler, Press, & Sciascia, 2006). Since the core is central to almost all sports activities, control of core strength, balance and motion should optimize upper and lower extremity function (Kibler et al., 2006). However, most core assessments are focused on isometric muscular endurance with long tension times and low loads (Carter, Beam, Mcmahan, & Brown, 2006). Given that most athletic upper body power generation involves high levels of neuromuscular activation/coordination of a rotational nature (Strockbugger & Haennel, 2001), it is important to assess athletic ability that replicates as closely as possible the rotational activity of an athlete. This contention provides the focus of this paper.

There is a paucity of research that has measured rotational power of the core. Andre et al. (2012) quantified core rotational power using a seated cable rotation technique, the authors reporting a high intraclass coefficient (ICC) between days of 0.97, 0.94, and 0.95 at 9, 12 and 15% bodyweight respectively in college male and female population. A limitation of the protocol used in this study was the use of the seated position, which most likely eliminated the involvement of some of the core stabilizers such as the glutei musculature, and therefore the associated hip and pelvis musculature that provides core stability in all three planes. The study of Palmer and Uhl (2011) addressed this limitation by quantifying the interday reliability of peak power using a chop and lift technique from a half kneeling position. The authors reported high ICC's for peak muscular power of the chop (range: 0.87-0.98) and lift (range: 0.83-0.96) between test sessions, as well a standard error of measurement (SEM) range of (28-41 W). Both studies have statistical limitations in that: a) reporting the ICCs gives no indication of the typical error associated with the respective assessments as in the study of (Andre et al., 2012); and b) both studies included non-athletic populations. However, the chop and lift can be considered a better movement compared to seated trunk rotation due to proximal stability (associated hip and pelvis musculature that provides core stability in maintaining an erect spine) being required for this type of movement (Voight et al., 2008). Given these limitations and the assertion that the chop and lift could provide valuable information regarding upper extremity rotational power, the purpose of this study was to establish the reliability of chop and lift power output as measured by a linear position transducer on participants highly accustomed to, and reliant on rotational power such as cricket.

Methods

Experimental Approach to the Problem

A linear position transducer was attached to the weight stack of a cable pulley system. Thereafter, eight professional male cricket players were assessed on three occasions separated by at least seven days. Intraclass correlation coefficients (ICCs) and coefficient of variations (CVs) were used to quantify the absolute and relative consistency of the testing procedures.

Participants

Eight male professional cricket players (age = 23$\pm$ 3.38 years, height =186$\pm$ 10.06 cm, mass=89.71$\pm$ 8.12 kg) with a resistance (more than 2 years) training background volunteered to participate in the study. Players reporting any major musculoskeletal injuries, as assessed by the team physiotherapist, three months prior to the test were not included. Players were right hand dominant and provided written informed consent to participate in the study. The ethics review board of Auckland University of Technology approved the study.

Procedures

A standardized general warm up (10 minutes) comprising of low to moderate intensity exercises involving the hips, trunk and the upper extremities, was used to prepare the participants for the assessment. Participants were then familiarized with the movements and were instructed to maintain an erect spine while performing both tests. A half kneeling position was used in this study, however, unlike (Palmer & Uhl, 2011) study, there was no emphasis on narrow base of support as long as the participants maintained a neutral spine throughout the movement. A low-density foam roll was used to support the weight-bearing knee for comfort (see Figure 2a-3b). The resistance for the chop was 15% of the individual's bodyweight and 12% for the lift as prescribed by (Palmer & Uhl, 2011). The resistance used for the lift is comparatively lower due to the complexity associated in the task. A cable pulley system (Life Fitness, USA) along with micro resistance plates (0.25kg to 5kg) and a long metal dowel (0.9kg) was used in the assessment protocol. Participants were allowed two practice trials each for chop and lift before the test trials. The chop assessment was performed prior to the lift. Participants were instructed to provide maximal explosive effort for each test and were tested twice on each side. The average of the two attempts was used for further analysis. Procedures were replicated on three separate testing sessions, which were performed at least seven days apart.

Data Analysis

A linear position transducer (Celesco, Model PT9510-0150-112-1310, USA) attached to the weight stack of the cable machine measured vertical displacement relative to the ground with an accuracy of 0.1 cm. Data was collected at a sample rate of 500 Hz by a computer based data acquisition and analysis program. The displacement-time data were filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 50 Hz, to obtain position. The filtered position data were then differentiated using the finite-difference technique to determine velocity (v) and acceleration (a) data, which were each successively filtered using a low-pass 4th-order Butterworth Filter with a cut-off frequency of 6 Hz (Winter, 1990; Cronin, Raewyn, & McNair, 2004). The force (F) produced was determined by adding the mass of the weight stack to the force required to accelerate the system mass. Following these calculations, power (P) was determined by multiplying the force by velocity at each time point ($P = F \cdot v$). Peak power was determined from the averages of the instantaneous values over the entire push-pull phase of the chop and lift (until end of movement i.e. end position as seen in Figures 2b and 3b). The external validity of the derived measurements from a linear position transducer has been assessed using the force plate as a “gold standard” device ($r = 0.81$-0.96) (Cronin et al., 2004, p. 590; Chiu, Schilling, Fry, & Weiss, 2004).

Statistical Analysis

Means and standard deviations (SDs) were calculated for all the results after the data collection. The two trials for all the lifts were averaged for the participants within the session, and the participant’s means for each lift were averaged to provide a group mean for each testing session. Percent change in the mean (CM) was reported to indicate the differences in the average performance between days. The coefficient of variation (CV) was reported to determine the absolute reliability. Relative reliability was quantified via the ICC. The level of acceptance for reliability for this study was an ICC $\geq$ 0.70 (Vincent, 1994) and a CV $\leq$ 15% (Stoke, 1985). Ninety percent confidence intervals were reported for all statistical analyses. Descriptive statistics and reliability measures were computed using Microsoft Excel 2007 (Hopkins, 2000).

Results

The change in mean observed in the chop assessment was between -0.2 to -11.4W between days (see Table 3). The CVs ranged from 9.2% to 19% and ICCs 0.54 to 0.83 between testing occasions. Variability of all measures of reliability increased over the three testing occasions for the right side, whereas the opposite was true of the left side.

In terms of the lift, the observed change in mean ranged from -10.9 to 7.4W between days. The CVs ranged from 7.4% to 16.3% and ICCs 0.74 to 0.89 between testing occasions for both right and left sides. Furthermore the lift performed on the right side seemed to be more consistent over all during testing sessions (see Table 3).

Table 3: Reliability of the Chop and Lift mean peak power output.

Stages	Means and Standard Deviations			Test-Retest Reliability					
	Test 1	Test 2	Test 3	Test 2-1 % Change (90% CL)	Test 3-2 % Change (90% CL)	Test 2-1 CV (90% CL)	Test 3-2 CV (90% CL)	Test 2-1 ICC (90% CL)	Test 3-2 ICC (90% CL)
Chop Right Power (W)	466 (91.54)	458 (120.19)	409 (108.4)	-3.2 (-12.6 to7.5)	-11.4 (-27.4 to 9.7)	9.2 (6.2-20.5)	19.0 (13.4 to 47.3)	0.83 (0.31 to 0.979)	0.54 (0.27 to 0.90)
Chop Left Power (W)	494 (110)	440 (106)	437 (89)	-11.3 (-24.3 to 5.5)	-0.2 (-14.6 to 16.6)	15.1 (10.5 to 35.9)	14.1 (9.7 to 33.1)	0.56 (-0.25 – 0.91)	0.60 (-0.18 – 0.92)
Lift Left Power (W)	314 (95.3)	279 (83.1)	300 (90.9)	-10.9 (-25.0 to 7.2)	7.4 (-1.0 to 17.2)	16.3 (11.4 to 39.2)	7.4 (5.0 to 16.3)	0.74 (0.07 to 0.95)	0.94 (0.72 – 0.99
Lift Right Power (W)	279 (80.5)	277 (95.7)	279 (96.5)	-2.5 (-13.3 to 9.8)	0.6 (-11.4 to 14.2)	10.5 (7.2 to 23.8)	11.3 (7.8 to 26)	0.89 (0.50 to 0.98)	0.89 (0.51 to 0.98)

Discussion

Of interest to these researchers was the utility of the chop and lift as a measure of rotational power. A number of factors must be taken into account before considering such a movement, one of which is the reliability of the testing procedures. Previous researchers Palmer and Uhl (2011) have quantified the reliability of the chop and lift using a non–athletic population and an isotonic dynamometer. A major limitation in this study was the sample used – male and females between 18 and 65 years of age. Such a heterogeneous sample and in particular male-females (bi-polar plots) will artificially inflate the value of correlations such as the ICC. Secondly the use of an isotonic dynamometer limits the application of their results due to the non-specificity of the contraction type and accessibility to such expensive equipment. Addressing these limitations, this study was the first to include professional male athletes (cricketers) and incorporate a linear position transducer to assess the reliability of this movement.

In terms of the chop, the mean peak power outputs observed in this study (see Table 3) were higher (409 - 494W) to those reported by Palmer and Uhl (2011) – (346 - 395W). A similar pattern was observed for the lift, the mean peak powers for this exercise also substantially greater (277 - 314W) than the (Palmer & Uhl, 2011) study – (181 - 223W). The greater peak power outputs of this study could be attributed to a number of factors such as: a) athletic status of sample i.e. professional male cricketers vs. general population comprising both males and females aged 18-65 years; b) equipment used to quantify rotational power – linear position transducer vs. isotonic dynamometer; and c) differences in approaches to calculating power output (repetition max: Palmer & Uhl, 2011).

Stokes (1985) stated that a usual CV for biological systems is between 10 and 15%, most of the values of our study falling within these boundaries: 9.2-19%, chop; 7.4 – 16.3%, lift. There appeared to be no systematic change in the CVs between testing occasions, suggesting no familiarization and learning effects. Palmer and Uhl (2011) did not report CVs, however, they did report standard errors of measurement (SEM) for the chop (28-34W) and lift (41-52W). The corresponding measures for this study were higher for the chop (37.4-61.7W) and lower for the lift (23.6-45.6W). The increased variability for the chop in this study can most likely be explained by variable end range deceleration due to some athletes avoiding hitting the top of the cable pulley. This was not a problem with the lift due to the movement-load selection. Equipment and test/load selection needs to consider such human factors.

Vincent (1994) suggested that ICC values above or equal to 0.70 might be considered reliable; all the lift ICCs above this benchmark except the chop ICC measurements meeting this threshold. The ICCs reported in this study (0.54-0.83) were considerably lower than those reported by (Palmer & Uhl, 2011), who reported ICCs of 0.87-0.98, the disparity in results can most likely be attributed to the sample characteristics. ICCs provide insight into the change in rank order of the participants, the participants of the Palmer and Uhl (2011) study unlikely to change in rank order given their heterogeneity. This is evident in their data sets with standard deviations nearly half the mean, and ranges in power output from 45-835W. However, small changes in power output in the current study most likely depicting larger effects on rank order due to homogeneity and the smaller sample size.

Practical Applications

The lift assessment has shown acceptable reliability between days and therefore can be used by strength and conditioning practitioners in developing and evaluating upper extremity/trunk strength and power. However, the chop assessment has shown high variability between days in this study and therefore requires further investigation regarding load (mass), equipment design and technique. Future research should focus on establishing the optimum load for the chop assessment, as the 15% load for the chop appeared too light for cricketers who have a strong background in resistance training. In addition careful consideration needs to be given to equipment constraints in relation to the anthropometry of the sample of interest. Researchers may also consider exploring movement's that are confined to trunk movement only, allowing less involvement of the distal segment, which in turn should decrease the movement variability and isolate trunk contribution. This may address some of the limitations faced in this study such as "topping out on the weight stack". Additionally, the use of pneumatic air resistance compared to a standard cable pulley could provide significant advantage in avoiding excessive end range deceleration and topping of weight as mentioned earlier. The pneumatic machines such as functional trainers do not need additional weight plates to be attached and therefore could be more convenient in testing upper extremity/trunk power compared to a standard cable pulley.

CHAPTER 4

THE ROLE OF ROTATIONAL POWER AND MOBILITY ON THROWING VELOCITY

Introduction

Batting, bowling and fielding can be considered to be the three pillars of cricket. Of interest is the fielding component of the game, in particular the throwing aspect of cricket. The ability of the players to consistently throw at high velocity, with accuracy, is considered to be a challenging task that can influence the outcome of a game (Cook & Strike, 2000). Improved force output and rate of force development in the appropriate muscles can result in increased throwing velocity (Newton & McEvoy, 1994). Due to the kinetic linkage of proximal to distal sequence in throwing (Putnam, 1993), it is important for the force to be transferred sequentially from the proximal segments, such as the hips, towards the more distal segments, such as the shoulders and arms. Therefore optimum mobility of the proximal segments, such as the hips and upper trunk, may be crucial to throwing velocity. Of interest to the authors is whether rotational mobility and/or power influence throwing velocity among cricketers.

Lack of flexibility in athletes has been related to decrease in performance (Shellock & Prentice, 1985). Therefore the role of thoracic and hip rotational mobility could play a significant role in any throwing activity. Since a sequential pattern of proximal-to-distal is observed in most throwing and striking sports (Putnam, 1993), it is important to identify the role of rotational mobility in various segments, especially the hips and the thoracic spine, that allow the greatest rotation due to the orientation of the joints (Sahrmann, 2002). In this regard, a seated bar in front rotational test with high reliability

(ICC > 0.80) can be used to give some indication of thoracic mobility (Johnson et al., 2012). Similarly a seated hip rotational assessment has also been incorporated successfully (Launder et al., 2010) and considered highly reliable: ICCs: 0.93 and 0.96; CVs: 12.3% and 8.3% (Pua et al., 2008). However, no researcher to the knowledge of these authors has investigated the role of hip and thoracic mobility on cricket ball throwing velocity.

The ability to rapidly produce force in the transverse plane can be considered rotational power. Sports that involve throwing movements can be considered rotational power sports due to the requirement of explosive movements in either the transverse or oblique planes (Earp & Kraemer, 2010). Implements such as the medicine ball and cable pulleys can be very useful in developing and quantifying rotational power as they allow motion in all three planes. Rivilla-Garcia et al. (2011) reported a high correlation (r=0.90) between a light overhead medicine ball throw (0.8kg) and handball throwing velocity. Conversely Kohmura et al. (2008) reported that the scoop medicine ball throw had very little shared variance with baseball fielding (throwing distance, standing long lump and agility T test) (~7%) compared with batting (~46%). It can be noted that task specificity and weight of the medicine ball may be practically important when quantifying the influence of the medicine ball throw on throwing velocity.

Similarly the chop and lift can also be considered a rotational power assessment task given the dynamic control required in all three planes (Cook & Fields, 1997). Rotational power assessments such as medicine ball throws (side, overhead, scoop) and the chop and lift have shown high reliability: ICC=0.84 to 0.99 (Kohmura et al., 2008; Lehman et al., 2013; Rivilla- Garcia et al., 2011), ICC= 0.87 to 0.98 (Palmer & Uhl, 2011) respectively. There are currently no studies investigating the influence of the chop and lift on cricket ball throwing velocity. In addition, further research regarding the reliability of the chop and lift assessment may be necessary among the athletic population.

Given the limitations cited previously, the purpose of this paper is to investigate the role of upper body rotational power, thoracic and hip mobility on cricket ball throwing velocity. It is hypothesized that athletes who throw faster will have a greater rotational mobility and power capacity. The findings from this study should give insight into assessment and exercise prescription for the rotational athlete (baseball and cricket) interested in improving throwing velocity.

Methods

Experimental Approach to the Problem

The rotational mobility and power of professional and under-19 club level male cricket players were assessed on one occasion. A linear position transducer (Celesco, Model PT9510-0150-112-1310, USA) was attached to the weight stack of a cable pulley system (Life Fitness, USA) to measure chop and lift power. Seated/standing cricket ball and medicine ball throw velocity was measured using a radar gun (STALKER ATS II, USA). Seated active hip and thoracic rotation range of motion (ROM) was measured using an inclinometer and a goniometer respectively. Thereafter participants were divided into two groups (fast and slow) based on cricket ball throwing velocity. An independent T-test was used to determine between group differences on the variables of interest.

Participants

Eleven male professional cricket players (age= 23.8±2.27 years, height =183± 9.83 cm, mass= 88.5±7.25kg) and ten under-19 club level cricketers (age=17.78±0.44 years, height=178± 8.54cm, mass= 75.6±11.9 kg) volunteered to participate in this study. Players reporting any major musculoskeletal injuries, as assessed by the team physiotherapist in the three months prior to the test, were not included. All participants provided written informed consent, and the ethics review board of Auckland University of Technology approved the study.

Procedures

A standardized general warm up (10 minutes), comprising of low to moderate intensity exercises involving the hips, trunk and the upper and lower extremities, was used to prepare the participants for the assessments. Participants were then familiarized with the movements utilized in this study through verbal and visual instructions. Anthropometrical measurements were performed followed by standing and seated cricket ball throw, chop and lift, standing and seated medicine ball throw. The order of the assessments was based on neuromuscular requirements and complexity associated within each assessment (Miller, 2012). Participants were provided with two minutes of rest for all the power related assessments: cricket and medicine ball seated and standing throws and chop and lift (Miller, 2012).

Assessments

A half kneeling position (Palmer & Uhl, 2011) was used for the chop and lift assessment in this study. Unlike Palmer and Uhl's (2011) study there was no emphasis on narrow base of support as long as the participants maintained a neutral spine throughout the movement (rear aspect of the head and sacrum in a vertical line). A low-density foam roll was used to support the weight-bearing knee for the comfort of the participant (see Figure 2a-3b). The resistance for the chop was 15% of the individual’s bodyweight and 12 % for the lift (Palmer & Uhl, 2011). A cable pulley system (Life Fitness, USA) along with micro resistance plates (0.25kg to 5kg) and a long metal dowel (0.9kg) was used in the assessment protocol. Participants were allowed two practice trials each before the test trials for both chop and lift. The chop assessment was performed prior to the lift. Participants were instructed to provide maximal effort for each test and were tested twice on each side. The higher of the two attempts with regards to power output was used for analysis.

The overhead cricket ball throw (standing and seated) and side medicine ball throw (standing and seated) were performed on a cricket pitch (20.12m long). Participants were permitted one stride forward for the standing cricket ball throw, while maintaining the front foot behind the line until ball release. Participants were asked to throw the cricket ball into a net with no specific target. The primary objective of this study was to attain maximal throwing velocity and therefore no specific targets were set due to speed-accuracy trade-off (Freeston, Ferdinands, & Rooney, 2007) Outside factors such as approach speed, approach angle and ball pick up were excluded in this study (Freeston et al., 2007).

The side medicine ball throw was performed by grasping the medicine ball (19.6N) with both hands, rotating the trunk opposite to the throwing direction as in a countermovement, followed by rotating the trunk to the throwing direction attempting to throw the medicine ball as fast as possible (Ikeda et al., 2007) (see Figure 1a and b). Participants were asked to attempt two throws for both (seated/standing cricket and medicine ball throw) and the throw with a higher velocity was used for analysis. The seated cricket and medicine ball throws were performed on a box (30 inches/76.2 cm high) without the feet touching the surface of the floor (to eliminate lower extremity contribution). All the throws were performed on both sides. Participants were allowed two practice trials each for standing and seated cricket and medicine ball throws before the test trials.

The hip rotation ROM was performed on a box (30 inches/76.2 cm high) with the legs resting comfortably off the edge of the box. In a seated position, participants were asked to actively rotate the hips internally and externally whilst stabilizing the trunk and the hips placing their hands on the hips (see Figure 4a and b). The femur was stabilized to limit accessory motion, while the lower shank was rotated (internally and externally) until end ROM (Launder et al., 2010).

Seated thoracic ROM assessment (see Figure 5a and b) was performed on a box (30 inches/76.2 cm high) with the hips and knees flexed at 90° and a ball (20 cm diameter) was placed between the knees to minimize motion of the lower extremities during thoracic rotation (Johnson et al., 2012).

Data Analysis

A linear position transducer (Celesco, Model PT9510-0150-112-1310, USA) attached to the weight stack of the cable machine measured vertical displacement relative to the ground with an accuracy of 0.1 cm. Data was collected at a sample rate of 500 Hz by a computer-based data acquisition and analysis program. The displacement-time data were filtered using a low-pass 4th-order Butterworth filter with a cut-off frequency of 50 Hz, to obtain position. The filtered position data were then differentiated using the finite-difference technique to determine velocity (v) and acceleration (a) data, which were each successively filtered using a low-pass 4th-order Butterworth Filter with a cut-off frequency of 6 Hz (Winter, 1990; Cronin et al., 2004). The force (F) produced was determined by adding the mass of the weight stack to the force required to accelerate the system mass, Following these calculations, power (P) was determined by multiplying the force by velocity at each time point ($P = F \cdot v$). Average power was determined from the averages of the instantaneous values over the entire push-pull phase of chop and lift (until end of movement, i.e. end position).

The radar gun (STALKER ATS II, USA) was placed behind the participant, performing the throw to measure the ball release speed (km/h). In addition, a goniometer (plastic) and a digital inclinometer were used to measure thoracic and hip rotation ROM respectively. The goniometer was aligned parallel to the ground at the midpoint between T1 and T2 (thoracic vertebrae) spinous processes, with the spine of the scapula as a reference point. The range of motion was then measured with the moving arm of the goniometer while maximally rotating to one side (Johnson et al., 2012). A digital inclinometer providing 360° information with respect to the vertical axis, was used for the hip rotation ROM assessment (Launder et al., 2010).

Statistical Analysis

Means and standard deviations (SD) were used as measures of centrality and spread of data. Participants (n=21) were divided into two groups (fast: n=11 and slow: n=10) on the basis of their standing cricket ball throwing velocity. An independent t-test was used to determine between group-differences. An alpha level of 0.05 was used as the criteria measure for significance. All significant values (differences) for both dominant and non-dominant sides are provided in Table 4.

Results

The means, standard deviations and between group differences for fast and slow throwers can be observed in Table 4. The fast and slow throwing groups differed by 11.03 km/hour. Interestingly the differences observed in seated cricket ball throw between fast and slow throwers were significant (12.3%) and similar in magnitude to standing cricket ball throwing velocity. The faster throwers were on average 6 cm taller and ~9 kg heavier than their slower counterparts. However, all anthropometric differences were found to be statistically non-significant between groups

With regard to the rotational power measures, the standing medicine ball throw velocity was ~ 14% to 17% greater than the seated medicine ball throw in fast and slow groups respectively. Also greater power output (30.8% to 34.5%) was associated with the chop compared to the lift. Only the chop force (18.4%) and work (31.2%) measures were found to differ significantly between fast and slow throwers.

In terms of the ROM measures, hip external rotation ROM on the dominant side and bilateral thoracic rotational ROM (dominant and non-dominant), were found to differ significantly (11.7% to 16.8%) between groups. However, no significant difference was observed in hip internal rotation ROM.

Table 4: Fast vs. slow thrower differences

Fast and Slow Throwers				
Variables	Fast	Slow	Mean	P value
Stand cricket ball (km/h)	112±4.14	101±5.33	11.03	0.00*
Seated cricket ball (km/h)	86.6±4.77	75.9±4.27	10.7	0.00*
Mass (kg)	86.7±11.6	77.7±10	8.93	0.07
Age (years)	183±8.98	177±9.22	6.25	0.13
Height (cm)	81.9±5.75	77.7±4.82	4.21	0.09
Arm length (cm)	95.9±7.11	93.8±5.85	2.14	0.46
Leg length (cm)	33±3.70	31.6±2.84	2.21	0.14
Seated medicine ball (km/h)	39.6±3.7	38.3±2.18	1.33	0.33
Stand medicine ball (km/h)	113±28	92.5±16.7	20.8	0.05*
Chop force (N)	102±41	70±20.7	31.8	0.04*
Chop work (J)	419±125	354±64.9	65.2	0.15
Chop power (W)	2.15±0.38	2.11±0.21	0.04	0.78
Chop velocity (m/s)	0.85±0.14	0.82±0.11	0.03	0.55
Chop displacement (m)	76.52±25	63.8±23.8	12.8	0.25
Lift force (N)	68.4±27.5	57.9±22	10.4	0.35
Lift work (J)	290±92.7	232±101	58.1	0.18
Lift power (W)	2.02±0.36	1.82±0.40	0.21	0.22
Lift velocity (m/s)	0.83±0.14	0.73±0.13	0.11	0.09
Lift displacement (m)	33.3±5.08	38.9±7.28	-5.53	0.06
Hip internal rotation (º)	41.1±5.86	46.6±5.21	-5.47	0.04*
Hip external rotation (º)	56.6±10.9	68±6.38	-11.4	0.01*
Thoracic rotation non-dominant+ (º)	58.2±11	67.2±4.37	-9.02	0.03*

*Significantly different between groups

+Non-dominant side

Discussion

In terms of the cricket ball-throwing velocity, the mean peak velocities observed in this study (101 – 112 km/h) were very similar to those reported by Freeston et al. (2007) among elite (senior) and Under-19 cricketers (100.4 to 109.4 km/h). The mean peak side medicine ball throwing velocities of this study (38.3 km/h and 39.6 km/h) were very similar to those reported by Ikeda et al. (2009) among competitive throwers and baseball players (36.5 km/h and 41.4km/h) using a similar weighted medicine ball (2kgs). However, the differences in medicine ball throwing velocity (seated and standing) between the fast and the slow group were non-significant in this study. Nonetheless, it would seem the throwing ability of the participants used in this study were typical of other athletic populations.

It was hypothesized that greater rotational ROM at the hip and in the thoracic region, in combination with greater rotational power, would result in increased throwing velocity. Significant differences were noted in thoracic rotation (both sides) and hip external rotation (dominant side). However, it was observed that the faster throwers did not have greater ROM. Furthermore, force and work done during chop on the dominant side was significantly different between fast and slow throwers. No other power variables were found to differ significantly between groups. These findings are discussed in more detail herewith.

With regards to thoracic and hip rotation ROM, the mean seated bar in front position for the thoracic rotation ROM was found to be greater (56.6 to 68°) in this study compared to those reported (53.7 to 57.6°) by Johnson et al. (2012) study. Furthermore, active hip internal and external rotation ROM on the dominant side was also found to be greater in this study (internal rotation: 33.3° to 38.9° and external rotation: 41.1° to 46.6°)

compared to those reported by Ellenbecker et al. (2007) study (internal rotation: 23° external rotation: 34°) among professional baseball players. The differences observed in the hip rotation ROM values between both the studies could be sport specific or most likely be attributed to methodological dissimilarities between studies e.g. seated in this study versus prone in Ellenbecker et al. (2007) study.

In this study, significant differences were observed in active hip external rotation on dominant side and bilateral (both sides) thoracic rotation ROM between fast and slow throwers. However, the faster throwers in this study had smaller ROM compared to their slower counterparts. These findings are similar to Robb et al.'s (2010) study that reported moderate correlation ($r=0.50$, $p<0.04$) between lower total hip rotation arc PROM (passive range of motion) on the non-dominant side and throwing velocity among professional baseball pitchers. Excessive rotation at the hips can put the pelvis and foot in a more open position, thereby prematurely initiating the arm cocking phase and resulting in loss of kinetic energy in the lower extremity (Robb et al., 2010).

In terms of power output, the athletes of this study produced slightly higher peak power outputs (chop: 354 – 419W; lift; 232-290W) to those reported by Palmer and Uhl (2011) for the (non-athletic population) in their study (chop: 346- 395 W; lift: 181-223W). Significant differences were observed between fast and slow players regarding the chop (work and force) but not for the lift. These differences may be attributed to the fast throwers been heavier and taller and therefore the relative masses and distance that the load is moved is greater for this population, hence the results. It needs to be noted also, that there is a great deal of variability associated with the chop movement, the reader needing to be cognizant of this limitation. The inter-group differences in the other measure of rotational power (seated medicine ball throws) were found to be statistically non-significant.

Practical Applications

It was thought that greater rotational ROM at the hip and in the thoracic region, in combination with greater rotational power, would result in increased throwing velocity. In terms of ROM, greater ROM of the hip and thoracic region were not associated with greater throwing velocity. Therefore strength and conditioning professionals should be careful promoting excessive ROM in the proximal segments, as excessive ROM might be detrimental in transferring optimum power through the kinetic chain in an explosive task such as throwing. However, adequate ROM may be necessary to effectively carry out a throwing task due to the sequential pattern of proximal to distal linkage.

With regards to the rotational power measures used in this study and given the variability of the chop measures, it may be that rotational power may not be an important contributor to throwing velocity. Understanding the rotational contribution is further complicated by the inter-group anthropometric differences. The implications of these findings are that: 1) better measures/tests are needed to clarify the contribution of rotational power that control for anthropometric factors; and/or, 2) rotational power is not important but rather having a relatively stiff trunk that transfers the momentum generated in the lower body to the distal segments without energy leakage is more important. The ROM results would certainly support such a contention, those with reduced ROM at the hip and in the thoracic region producing greater throwing velocity.

In addition, significant differences were observed in this study with regards to seated cricket ball throwing velocity among fast and slow throwers suggest the importance of the upper extremity particularly the distal segment. A seated throwing position can reduce the involvement of proximal segments (trunk and legs) requiring greater contribution from the distal segments such as the arms and hands. Therefore future research should include assessments that quantify the contribution of the distal and proximal segments with regards to ROM and power output.

CHAPTER 5
SUMMARY, PRACTICAL APPLICATIONS AND FUTURE RESEARCH DIRECTIONS

Summary

Intuitively and as evidenced in the literature, conventional linear assessment of movement is of little value to rotational sport athletes. The initial objective of this thesis was to explore and review rotational power and mobility assessments such as medicine ball throw, chop and lift, seated hip and thoracic rotation ROM (Chapter 2). From the literature review it was surmised that these assessments were of great utility and for the most part considered reliable, though it was acknowledged that there was a paucity of research investigating the chop and lift, and no research had quantified both relative and absolute consistency between days in professional athletes. Furthermore, the influence of rotational power and mobility on functional performance was largely unexplored. These two findings provided the focus of the experimental chapters.

In Chapter 3, the interday reliability of chop and lift among professional cricketers was investigated. The absolute and relative consistency of the assessment using loads of 15% (chop) and 12% (lift) bodyweight were quantified. The lift (CV: 7.4%-16.3%, ICC: 0.74-0.94) was found to be more reliable between days compared to the chop (CV: 9.2%-19%, ICC: 0.54-0.83). It was suggested that further research on the chop assessment be undertaken given the limitations identified in this study.

The aim of Chapter 4 was to determine the influence of these rotational mobility and power variables on cricket ball throwing velocity. Participants were divided into two groups: fast and slow based on their cricket ball throwing velocity. The seated cricket ball throw was also found to be significantly different (12.3%) between fast and slow throwers. It was found that bilateral thoracic rotation ROM; hip external rotation ROM on the dominant side, force and work required in the chop was significantly different between fast and slow throwers. Faster throwers in this study displayed greater force (18.4%) and work (31.2%) outputs in the chop compared to slower throwers, however slower throwers showed significantly greater ROM in the thoracic (13.4% to 16.8%) and hip region (11.8%). In addition, anthropometrical (height and mass) differences between the groups may be attributed to the differences observed in force and work outputs in chop and seated cricket ball throwing velocity, but requires further investigation. It was concluded that greater ROM at proximal segments such as hips and thoracic may not increase throwing velocity in cricket as reduced ROM at proximal segments can be useful in transferring the momentum from the lower extremity in an explosive task such as throwing. Although cricket ball throwing was the primary focus of this thesis, the findings are most likely of practical significance to many throwing sport athletes.

Practical Applications

The lift assessment has shown to have high reliability and can be effectively used by strength and conditioning practitioners in developing and evaluating upper extremity strength and power in a transverse plane. Conversely, the chop assessment had high variability between days and therefore further investigation regarding load, equipment design and technique is required. In addition, the use of pneumatic air resistance machines such as functional trainers that do not need additional weight plates to be attached could be more convenient and practical in testing upper extremity trunk and power compared to a standard cable pulley used in this study.

Assessments involving both the distal and proximal segments can be more appropriate for cricket ball throwing velocity. Strength and conditioning professionals should look at the relative contribution of distal and proximal segment with regards to ROM and power. In addition, program design should emphasize adequate, rather than absolute ROM at proximal segments in order to optimize throwing velocity among cricketers.

Future Research Directions

It was clear from Chapter 2 that the chop assessment needs further investigation. There was a high variability observed in this study and therefore future researchers may consider exploring movement's that are confined to the trunk, allowing less involvement of the distal segment, which in turn should decrease the movement variability and isolate trunk contribution. This may also address some of the limitations faced in this study such as "topping out on weight stack".

With regards to strength, power and ROM, future research should investigate both proximal and distal segment contribution and thereafter assess the influence on cricket ball throwing velocity. In addition, future studies should carefully examine the load (mass) incorporated for both medicine ball and chop and lift assessments. Inappropriate weight can be detrimental in assessing the role of these assessments on throwing velocity. Once the role of these assessments/variables have been identified, then training studies that address the development of the variables of interest should be initiated. Correlating the change in these measures with the change in throwing velocity will provide valuable insight to the strength and conditioning coach and direct programming to better effect.

REFERENCES

Akutagawa, S., & Kojima,T. (2005). Trunk rotation torques through the hip joints during the one- handed and two- handed backhand tennis strokes. *Journal of Sports Science, 23*(8), 781-793.

Andre, M. J., Fry, A. C., Heyrman, M. A., Hudy, A, Holt, B., Roberts, C.,… & Gallagher, P. M. (2012). A reliable method for assessing rotational power. *Journal of Strength and Conditioning Research, 26*(3), 720-724.

Booth, L. (2005). A physiotherapy perspective on improving swing technique in a professional golfer: A case study. *Physical Therapy in Sport, 6*(2), 97-102.

Carter, J. M., Beam, W. C., Mcmahan, S.G., & Brown, L. (2006). The effects of stability ball training on spinal stability in sedentary individuals. *Journal of Strength and Conditioning Research 20*(2), 429-435.

Cook, D. P., & Strike, S. C. (2000). Throwing in cricket. *Journal of Sports Sciences, 18*(12), 965-973.

Cook, G., & Fields, K. (1997). Functional training for the torso. *Strength and Conditioning Journal*, *18*(12), 14-19.

Chiu, L. Z. F., Schilling, B. K., Fry, A. C., & Weiss, L. W. (2004). Measurement of resistance exercise force expression. *Journal of Applied Biomechanics*, *20*(2), 204-212.

Cronin, J. B., Raewyn, H. D., & McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research, 18*(3), 590-593.

DeRenne, C., & Szymanski, D. J. (2009). Effects of baseball weighted implement training: A Brief Review. *Strength and Conditioning Journal, 31*(2), 30-37.

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

Earp, J. E., & Kraemer, W. J. (2010). Medicine ball training implications for rotational power sports. *Strength and Conditioning Journal, 32*(4), 20-25.

Ellenbecker, T. S., Ellenbecker, G. A., Roetert, P. E., Silva, R. T., Keuter, G., & Sperling, F. (2007). Descriptive profile of hip rotation range of motion in elite tennis players and professional baseball pitchers. *The American Journal of Sports Medicine, 35*(8), 1371-1376.

Ellison, J. B., Rose, S. J., & Sahrmann, S. A. (1990). Patterns of hip rotation range of motion: A comparison between healthy subjects and patients with low back pain. *Journal of American Physical Therapy, 70*(9), 537-541.

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.

Gulgin, H. R., & Armstrong, C. W. (2008). Passive hip range of motion in LPGA golfers. *Clinical Kinesiology, 62*(2), 9-15.

Heneghan, N. R., Hall, A., Hollands, M., & Balanos, G. M. (2009). Stability and intra-tester reliability of an in vivo measurement of thoracic axial rotation using an innovative methodology. *Manual Therapy, 14*(4), 452-465.

Hoogenboom, B. J., Voight, M. L., Cook, G., & Gill, L. (2009). Using rolling to develop neuromuscluar control and coordination of the core and extremities of athletes. *North American Journal of Sports Physical Therapy, 4*(2), 70-82.

Hopkins, W. G. (2000). Reliability from consecutive pairs of trials (Excel spreadsheet*).* In: A new way of statistics. *A Peer- Reviewed Journal and Site for Sports Research*. Retrieved September12, 2013, from www.sportsci.org.

Ikeda, Y., Kijima, K., Kawabata, K., Fuchimoto, T., & Ito, A. (2007). Relationship between side medicine-ball throw performance and physical ability for male and female athletes. *Journal of Strength and Conditioning Research, 99*(1), 47-55.

Ikeda, Y., Miyatsuji, K., Kawabata, K., Fuchimoto, T., & Ito, A. (2009). Analysis of trunk muscle activity in the side medicine-ball throw. *Journal of Strength and Conditioning Research, 23*(8), 2231-2240.

Johnson, K. D., Kim, K. M., Yu, B. K., Saliba, S. A., & Grindstaff, T. L. (2012). Reliability of thoracic spine rotation range of motion measurements in healthy adults. *Journal of Athletic Training, 47*(1), 52-60.

Kibler, W. B., Press, J., & Sciascia. (2006). The role of core stability in athletic function. *Sports Medicine, 36*(3). 189-198.

Kohmura, Y., Aoki, K., Yoshigi, H., Sakuraba, K., & Yanagiya, T. (2008). Development of a baseball- specific battery of tests and a testing protocol for college baseball players. *Journal of Strength and Conditioning Research, 22*(4), 1051-1058.

Kouyoumdjian, P., Coulomb, P., Sanchez, T., & Asencio, G. (2012). Clinical evaluation of hip joint rotation range of motion. *Orthopedics & Traumatology Surgery & Research, 98*(1), 17-23.

Launder, G. K., Moore, D. S., Sipes, R. C., & Meister, K. (2010). Functional hip characteristics of baseball pitchers and position players. *The American Journal of Sports Medicine, 38*(2), 383-387.

Lehman, G., Drinkwater, E. J., Behm, D. G. (2013). Correlation of throwing velocity to the results of lower- field-tests in male college baseball players. *Journal of Strength and Conditioning Research, 27*(4), 902-908.

Miller, T. (2012). *NSCA's guide to tests and assessments* Champaign, IL: Human Kinetics.

Myers, J., Lephart, S., Tsai, Y. S., Sell, T., Smoliga, J., Jolly, J. (2008). The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sport Sciences, 26*(2), 181-188.

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.

Nuzzo, J. L., McBride, J. M., Cromie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometeric and dynamic tests of strength. *Journal of Strength and Conditioning Research, 22*(3), 699-707.

Palmer, T. G., & Uhl, T. L. (2011). Interday reliability of peak muscular power outputs on an isotonic dynamometer and assessment of active trunk control using the Chop and Lift tests. *Journal of Athletic training, 46*(2), 150-159.

Palmer, T. G. (2012). *Effects of proximal stability training on sport performance and proximal stability measures* (Unpublished doctoral dissertation). University of Kentucky, Lexington, KY. Retrieved from http://www.mc.uky.edu/rehabsciences/docs/dissertations/Palmer,%20T_Dissertations_2012.pdf.

Pua, Y., H., Wrigley, T. W., Cowan, S. M., & Bennell, K. L. (2008). Intrarater test-retest reliability of hip range of motion and hip muscle strength measurements in persons with hip osteoarthritis. *American Academy of Physical Medicine and Rehabilitation, 89*(6), 1146-1154.

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. *Journal of Biomechanics, 26*(1), 125-135.

Robb, A. J., Fleisig, G., Wilk, K., Macrina, L., Bolt, B., & Pajaczkowski. (2010). Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball. *The American Journal of Sports Medicine, 38*(12), 2487-2493.

Rivilla-Garcia, J., Martinez, I., Grande, I., & Sampedro- Molinuevo, J. (2011). Relationship between general throwing tests with a medicine ball and specific tests to evaluate throwing velocity with and without opposition in handball. *Journal of Human Sport and Exercise, 6*(2), 414-426.

Sahrmann, S. (2002). *Diagnosis and treatment of movement impairment syndromes.* St. Louis, Missouri: Mosby.

Shellock, F. G., & Prentice, W. E. (1985). Warming- up and stretching for improved physical performance and prevention of sports- related injuries. *Sports Medicine, 2*(4), 267-278.

Stodden, D., Campbell, B., & Moyer, T. (2008). Comparison of trunk kinematics in trunk training exercises and throwing. *Journal of Strength and Conditioning Research, 22*(1), 112-118.

Stokes, M. (1985). Reliability and repeatability of methods for measuring muscle in physiotherapy. *Physiotherapy Theory and Practice, 1*(2), 71-76.

Strockbugger, B. A., & Haennel, R. G. (2001). Validity and reliability of a medicine ball explosive power test. *Journal of Strength and Conditioning Research, 15*(4), 431-438.

Szymanski, D. J., Szymanski, J. M., Bradford, J., Schade, R. L., & Pascoe. (2007). Effect of twelve weeks of medicine ball training on high school baseball players. *Journal of Strength and Conditioning Research, 21*(3), 894-901.

Tillaar, R. V. D., & Ettema, G. (2009). A comparison of overarm throwing with the dominant and non-dominant in experienced team handball players. *Perceptual and Motor Skills, 108*(3), 836-850.

Miller, T. (2012). *NSCA's guide to tests and assessments* Champaign, IL: Human Kinetics.

Vad, V. B., Bhat, A. L., Basrai, D., & Gebeh, A., Aspergen, D., & Andrews, J. R (2004). The role of associated hip and low back range of motion deficits. *The American Journal of Sports Medicine, 32*(2), 494-497.

Vincent, W. J. (1994). *Statistics in Kinesiology*. Champaign, IL: Human Kinetics.

Voight, M. L., Hoogenboom, B. J., & Cook, G. (2008). The chop and lift reconsidered: integrating neuromuscular principles into orthopedic and sports rehabilitation. *North American journal of Physical Therapy, 3*(3), 151-159.

Winter, D. A. (1990). *Biomechanics and motor control of human movement*. New York, NY: Wiley.

APPENDICES

Appendix 1- Ethical Approval

A U T E C
S E C R E T A R I A T

17 June 2013

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **13/110 The role of rotational power and mobility on throwing velcoity,**

Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 17 June 2016.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online throughhttp://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 17 June 2016;

- A brief report on the status of the project using form EA3, which is available online throughhttp://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 17 June 2016 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Madeline Banda
Acting Executive Secretary
Auckland University of Technology Ethics Committee
Cc:Kaushik Talukdar kaushik.talukdar21@gmail.com

Appendix 2- Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

22/06/2013

Project Title

The role of rotational power and mobility on throwing velocity

An Invitation

I am Kaushik Talukdar currently undertaking my Master Thesis at Auckland University of Technology. As part of my thesis I am required to complete a research, which will help me attain a Master's degree in Sport and Exercise Science. I would appreciate if you participate in my research as it can benefit many in terms of knowledge and improved cricket specific physical conditioning. The participation is voluntary and you may withdraw at any time.

What is the purpose of this research?

The primary purpose of this research is to develop a reliable test battery to measure rotational mobility and power in cricket and thereafter to see the influence of these tests on throwing velocity. There has been no standard protocol for measuring rotational power in cricket and therefore this research is targeted towards informing rotational assessment and programming to improve physical conditioning of cricketers.

How was I identified and why am I being invited to participate in this research?

The Auckland Cricket Association as a potential candidate has identified you. The requirements for participation in this research are: a) no current musculoskeletal injuries in the last three months b) minimum of two years club cricket experience at a premiere level/ graded.

What will happen in this research?

This research will require you to perform three rotational tests namely: a) chop and lift test; b) medicine ball throw; c) seated and standing cricket ball throw along with some basic measurements such as height, weight, limb length (legs and arms), hip and thoracic range of motion. The research aims to look at role of the above-mentioned parameters on throwing velocity, so that an optimal rotational test battery can be designed for cricketers. Most participants will only have to report for testing on one occasion (1.5. hours) whereas 8 participants will have to report on three separate occasions. Your identity will not be disclosed at any stage. You will be given a number to de-identify your identity and maintain privacy. Day one of the assessment will include the measurements of weight, height, limb length, hip and shoulder range of motion. Then a warm-up will occur and thereafter demonstration and familiarisation with the medicine ball throw and the chop and lift. Following the familiarisation you will perform cricket ball throw, medicine ball and chop and lift. You will be given 2 trials for each exercise per side and 120 seconds between trials.

What are the discomforts and risks?

The discomforts associated in this research will be mild since you will be required to have a minimum of two years of resistance training experience and will be free of any musculoskeletal injuries. Discomfort associated with testing could be fatigue and mild muscular soreness. However, this is unlikely given your training status.

How will these discomforts and risks be alleviated?

Proper demonstration, coaching cues, and practice trials will be provided to you prior to testing. Technical instruction will be provided in detail so that you will be comfortable during the tests.

What are the benefits?

This research will provide valuable insight into cricket specific assessment for rotational power, which could potentially inform strength and conditioning practice and improved performance in cricketers.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Your identity will remain protected throughout the course of the research; you will be assigned a number to which you will be referred to throughout the research. Once the number is assigned to you, anyone else involved in the research (i.e. supervisors / data analysers / research assistants etc.) will only have access to the number. Researchers will keep information confidential and secure from interception by unauthorised persons. Apart from storage in the SPRINZ database for potential future research use, information obtained will not be used for purposes other than the approved research. You will receive results of all tests you undertake at the completion of data collection

What are the costs of participating in this research?

The tests will be conducted on a day or a particular time of a day that does not affect your work, studies or any personal commitments, which could cause any financial discomfort. The tests will be conducted in your training facility, which would avoid any travelling commitments

What opportunity do I have to consider this invitation?

One-month will be provided to you prior to the tests to help you organize your time for the assessment days.

How do I agree to participate in this research?

You will be provided a consent form, which needs to be completed and sent to me via email. After the consent form is completed we can organize the time for the assessments

Will I receive feedback on the results of this research?

You will be provided all the test results after the completion of data collection. Comprehensive feedback in terms of your result will be provided via email.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John Cronin, AUT SPRINZ, *john.cronin@aut.ac.nz*, 9219999 ext 7523

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, *rosemary.godbold@aut.ac.nz* , 921 9999 ext 6902.

Whom do I contact for further information about this research?

Researcher Contact Details:

.

Kaushik Talukdar, email – *kaushik.talukdar21@gmail.com* Phone -021-0451469

Project Supervisor Contact Details:

Professor John Cronin, *john.cronin@aut.ac.nz*, 9219999 ext 7523

Approved by the Auckland University of Technology Ethics Committee on 17 June 2013, AUTEC Reference number: 13/110.

Appendix 3- Participant Consent forms

Parent/Guardian Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***The role of rotational power and mobility on throwing velocity***

Project Supervisor: ***Professor John Cronin***

Researcher: ***Kaushik Talukdar***

○ I have read and understood the information provided about this research project in the Information Sheet dated 22/06/13.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I am not suffering from any illness or injury that impairs my physical performance

○ I am currently playing cricket at a club level

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: ....………………………………………………………

Participant's name: ....………………………………………………………

Participant's Contact Details (if appropriate):
………………………………………………………………………………………..
………………………………………………………………………………………..
………………………………………………………………………………………..

……………………………………………………………………………………………..
Date:
Approved by the Auckland University of Technology Ethics Committee on 17 June 2013, AUTEC Reference number: 13/110 The Participant should retain a copy of this form.

Parent/Guardian Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***The role of rotational power and mobility on throwing velocity***

Project Supervisor: ***Professor John Cronin***

Researcher: ***Kaushik Talukdar***

○ I have read and understood the information provided about this research project in the Information Sheet dated 22/04/13
○ I have had an opportunity to ask questions and to have them answered.
○ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
○ If my child/children and/or I withdraw, I understand that all relevant information including tapes and transcripts, or parts thereof, will be destroyed.
○ I agree to my child/children taking part in this research.
○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Child/children's name/s :
…………………………………………………………………………………
…………………………………………………………………………………………
………………………………...
Parent/Guardian's signature:
.....................................…………………………………………………………
Parent/Guardian's name:
.....................................…………………………………………………………
Parent/Guardian's Contact Details (if appropriate):
……………………………………………………………………………………..
……………………………………………………………………………………..
……………………………………………………………………………………..
……………………………………………………………………………………..
Date:

Approved by the Auckland University of Technology Ethics Committee on 17 June 2013, AUTEC Reference number 13/110
Note: The Participant should retain a copy of this form.