The effect of coupled shoulder girdle and hip extensor strength training on sprint performance and ball speed in youth field hockey players

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Abstract

Sprint performance is important in many team sports including field hockey. Despite this, so far no studies have examined the effect of strength training on sprint performance in this cohort. Previous studies in other sports have shown a positive association between the increases in lower body strength and improvements in sprint performance. An often overlooked aspect of sprinting is the role of the upper extremities in the sprint action. Another key skill in field hockey is shooting where a player's ability can be evaluated based on ball velocity and the time taken to execute a shot. Similarly to sprinting no studies have examined the effect of strength training on ball speed in field hockey. Research looking at both sprinting and ball striking in other sports have highlighted the importance of both the shoulder girdle and hip extensor musculature. Therefore it was the aim of this thesis to ascertain whether strengthening the hip extensors and shoulder girdle specifically could improve both sprint performance and ball speed in youth hockey players and establish inter-relationships between sprint speed, ball velocity, shoulder girdle and hip extensor strength in hockey players. Chapter 3 presents the reliability for two novel isometric assessments, the isometric lateral pulldown (ILP) and isometric hip thrust (IHT), amongst 10 male participants with at least 2 years of structured resistance training. The IHT had a relatively small (6%) mean difference (MDiff) and effect size ([ES] 0.14) indicating moderate to good reliability between testing sessions. A test-retest intraclass correlation (ICC) of 0.97 in combination with a coefficient of variation (CV) of 7.3% indicated a small average variability. A small MDiff (4%) and ES (0.17) are indicators of good reliability for ILP's inter-session performance. While an ICC of 0.9 and a CV of 8.1% indicated that the average variability between sessions was small. Using these methods Chapter 4 determined the relationship between impulse generated and both sprint and ball striking performance in 23 youth male secondary school representative youth field hockey players. No significant relationships were found between sprint times and either of the isometric strength measures. Significant (p=0.000) large and positive correlations (r=0.68) were found between forehand ball release speed and isometric hip thrust results. Significant (p=0.046) moderate and positive correlations (r=0.42) were found between forehand ball release speed and isometric lateral pulldown results. Significant (p=0.025) moderate and positive correlations (r=0.47) were found between reverse ball release speed and isometric hip thrust results. Chapter 5 investigated the effects of a five week specialised strength training programme, targeting the shoulder girdle and hip extensor, on sprint performance and ball speed in a group of 10 youth male secondary school representative youth field hockey players. The programme resulted in significant large and positive improvements in both isometric hip thrust (p=≤0.000, ES = 1.21, +52.6%) and isometric lateral pulldown (p=0.007, ES = 1.46, +63.4%) and non-significant trivial

and small positive improvements in forehand and reverse ball speed respectively (*p*=0.813, ES = 0.09, +1.15%, *p*=0.303, ES = 0.27, 4.95%). However, significant small and negative decrements were experienced in 10-m (*p*=0.03, ES = 0.57, 2.67%), 30-m (*p*=0.016, ES = 0.44, 2.21%) and 40-m (*p*=0.016, ES = 0.43, 2.24%) sprint performance while non-significant (*p*=≤0.07) small and negative decrements (ES = 0.31, 1.55%) were found for 20-m. For this thesis it was determined that strengthening the shoulder girdle and hip extensors specifically may increase ball speed but not sprint performance in youth hockey players.

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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 extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Chapters 2 through 5 of this thesis represent four separate papers that have either been published, have been submitted, or will be submitted to peer-reviewed journals for publication. My contribution to these works, and that of the various co-authors, are outlined on the following pages and have been approved the inclusion of the joint work in the body of this masters' thesis.

Signed ....

Date 4 December 2017 ....

Candidate contributions to co-authored publications

Chapter 3.

Anyadike-Danes, K., Harris, N. Reliability of an isometric hip thrust and lateral pulldown. *International Journal of Sports Physiology and Performance,* Submitted.	Anyadike-Danes, K. (90%) Harris, N. (10%).

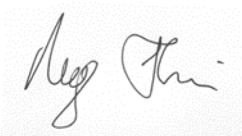
Chapter 4.

Anyadike-Danes, K., Harris, N., Gamble, P. Relationship between hip extensor and shoulder girdle strength, and sprint times and ball hitting speed in youth field hockey athletes. *Journal of Sports Sciences,* Submitted.	Anyadike-Danes, K. (85%) Harris, N. (10%) Gamble, P. (5%).

Chapter 5.

Anyadike-Danes, K., Harris, N., Gamble, P. Effect of 5 weeks of hip and shoulder girdle dominant training on sprint performance and ball release velocity. *Journal of Sports Science and Medicine,* Submitted.	Anyadike-Danes, K. (85%) Harris, N. (10%) Gamble, P. (5%).

Kechi Anyadike-Danes



Nigel Harris

Paul Gamble

Dedication

I would like to dedicate this masters to my recently departed grandmother Muriel Anyadike.

Words cannot describe what you meant to me therefore I will not try. This is but a simple show of my gratitude for all the times I needed you and you were there for me.

Acknowledgements

Though my name alone features on the cover of this thesis none of it would have been possible without many others who helped and believed in me even when I did not. Therefore in this section I would like express my gratitude to those whom without this journey, that started so long ago and has yet not finished, would not have been possible.

Firstly I would like to thank my primary supervisor, Nigel Harris, who without hesitation took me on. Though the circumstances that brought us together were not ideal throughout this entire process you have always been there to support me no matter whether they were major problems or minor problems I thought were major. Thank you for always being so free with your time and helping me to really appreciate the entire academic journey warts and all. It truly has been a pleasure to work with you.

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ETHICAL APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC; #16/358) originally on 26 October 2016.

CHAPTER 1

Introduction

Background to problem

Elite male field hockey players can spend up to five percent of match time in high-intensity striding and sprinting (Spencer et al., 2004). However, no studies have yet examined the effect of strength training on sprint performance in this cohort. A 2014 meta-analysis (Seitz, Reyes, Tran, Saez de Villarreal, & Haff, 2014) found that in adults there was very large correlation between improvements in squat strength and sprint performance (over 50-m). This would seem to suggest that there is transfer between lower-body strength training and sprint performance. A possible underpinning mechanism is that increased strength leads to an increase in force production, impulse and rate of force development (RFD) which are influential in sprint performance (Hunter, Marshall, & McNair, 2005). In their meta-analysis Seitz et al. (2014) found that lower body resistance training was able to reduce sprint times in elite and international athletes by a mean of 4.07 ± 2.02 % and 2.34 ± 0.83 %. Within elite level athletes enhancements of as little as 0.3-1.5% have been found to be worthwhile (Hopkins, 2005). However, it should be noted that in youth athletes resistance training has only been found to have small effects on linear sprint and sport-specific performance (standardised mean difference weighted mean (SMD_{wm})=0.58 and 0.75 respectively) (Lesinski, Prieske, & Granacher, 2016).

The role of the upper extremities in sprinting has not been investigated thoroughly. For running it has traditionally been thought that the arms provide balance and stability to the runner in motion, counterbalance the rotational forces of the torso during the stance phase, stabilise the torso and assist in the generation of forward momentum during the running cycle (Nicola & Jewison, 2012). It has been suggested that during running the arms may contribute a small (5-10%) but important part to the total vertical impulse generated by the body during the contact phase (Hinrichs, Cavanagh, & Williams, 1987). This upward acceleration or lift is advantageous as it allows the leg drive to be directed more horizontally and was found to increase as running speed increased. To date only one study has looked at the relationship between an upper-body strength measure and sprint speed, reporting a significant correlation between bench press power and 36.6-m sprint performance (Luhtanen & Komi, 1978).

The effectiveness of any shot in field hockey is thought to be determined by three different parameters: ball velocity, accuracy in reaching the goal or intended teammate and the movement duration (a shorter time limits the opportunities for an opponent to intercept) (Bretigny, Leroy, Button, Chollet, & Seifert, 2011). However, like sprinting, no studies have examined the relationship between strength and ball velocity or the effect that strength training has on it. Two common types of shots are the forehand which is distinguished by the hands being joint at the top of the stick and the reverse shot where the reverse side of the stick is used to shoot with the player's non-dominant side (Bretigny, Seifert, Leory, & Chollet, 2008). The forehand shot is the most powerful and is predominantly used for shooting at the goal and long range passing. The few biomechanical studies that have looked at the forehand shot have found that it is performed in a manner similar to that of a golf or baseball swing in that it consists of an initial backswing followed by a downswing and then a follow through (Franks, Weicker, & Robertson, 1985).

Though no research has specifically looked at the effect of strength or strength training on ball velocity in field hockey, the relationship between strength and power on implement head speed (IHS) has been examined. While limited a number of studies have also investigated the effect of different types of training interventions on IHS. It seems that maximal strength both in the upper and lower body, as assessed through non-specific compound movements, has moderate correlations to IHS (Keogh et al., 2009; Miyaguchi & Demura, 2012). Both golf and a hockey forehand shot feature a downswing phase, with the purpose being to return the club head to the ball after the backswing with maximum velocity (Hume, Keogh, & Reid, 2005). During this phase in golf it has been found that of the muscles measured, using electromyography (EMG), in the lower body the most active is the glutei maximus, with the upper and lower portions reaching 100% and 98% of maximum voluntary contraction (MVC) respectively (Bechler, Jobe, Pink, Perry, & Ruwe, 1995). Hockey also shares certain kinematic similarities with baseball where it has been found that during the swing phase the latissimus dorsi is one of the most active muscles in the upper body (90%-100% maximum voluntary isometric contraction (MVIC)) (Reyes, Dickin, Crusat, & Dolny, 2011).

Significance and purpose of research

While the strength of the relationship may vary between studies, there seems to be a consensus that a significant correlation exists between lower body strength and short sprint performance (≤50-m) in adult athletes (Seitz et al., 2014). So far due to a lack of research and different methodologies no such relationship has been well established in youth athletes. A more substantial amount of research however has examined the effect of lower body strength training on sprint performance in youth athletes. While strength training has been found to improve sprint performance to some degree only one study so far has focused on increasing hip extensor strength. Furthermore the majority of research in both adult and youth athletes has been performed in only a small number of sports, with field hockey currently not yet having been explored.

Aside from sprinting ball striking also plays another important role in a number of sports including field hockey. Currently only a limited number of correlational studies exist with the majority being performed using adult golfers. Therefore it is not certain whether the relationships found between both shoulder girdle and hip extensor strength and IHS exist in other ball striking sports such as field hockey. Similarly while it is difficult to draw any conclusions, with such a limited number of studies available, it would seem that strength training can improve IHS and therefore ball speed. However, the current studies have primarily looked at using full body workouts, not targeted hip extensor and shoulder girdle exercises, and have been performed using adults.

As outlined while research does exist on the effect of strength training on sprint performance and ball speed in a variety of sports, there is a lack of research in the sport of field hockey. Therefore the primary purpose of this thesis was to investigate the effects of five weeks of specialised strength training (specifically targeting the shoulder girdle and hip extensors) on sprint speed and ball velocity in youth field hockey players. A secondary purpose was to investigate the inter-relationships between two sport-specific performance measures, sprint speed and ball velocity, and two strength measures, shoulder girdle strength and hip extensor strength, in youth field hockey players. For the purpose of this study youths are all individuals that chronologically under the age of 18, including both adolescents and children (Granacher et al., 2016).

Thesis aims

Specifically this thesis shall:

1) Determine the reliability of an isometric lateral pulldown and isometric hip thrust;
2) Establish the relationship between impulse generated on the isometric lateral pulldown and both sprint performance and ball speed;
3) Establish the relationship between impulse generated on the isometric hip thrust and both sprint performance and ball speed;
4) Ascertain whether strengthening the hip extensors and shoulder girdle specifically can improve both sprint performance and ball speed in youth hockey players

Thesis structure

This thesis is comprised of a series of chapters that include a narrative review (Chapter 2) and three experimental studies (Chapters 3, 4 and 5). A visual layout of the thesis structure can be seen in figure 1. While this thesis will be submitted for pathway one it is presented using a pathway two format as the three experimental studies are to be submitted to journals for publication. The final chapter (Chapter 6) is a general discussion and gives an overview of the studies, how their findings might influence practice and considerations for future research.

Chapter 2: A broad narrative review that will explore the role of strength in both sprinting and ball striking. The review discusses briefly the idea of force transmission through the thoracolumbar fascia which connects the shoulder girdle, primarily the latissimus dorsi, and the hip extensor complex, primarily the gluteus maximus. This idea will be used to broadly explore the importance of these muscles in sprinting and ball striking, the relationship between the strength of these muscles and performance in these movements and finally how strengthening them may improve performance. This review will form the basis for the subsequent experimental chapters in the thesis.

Chapter 3: An experimental study that will look to establish the reliability of two novel isometric assessments, the isometric lateral pulldown and the isometric hip thrust. The test-retest reliability of these assessments is needed so as to ascertain the repeatability of the methods which will be used in the following chapters.

Chapter 4: An experimental study that integrates the methods outlined in Chapter 3 to determine the relationship between impulse generated and both sprint and ball striking performance in youth field hockey players. This chapter describes both the type and strength of the relationship between these different measures and gave insight into the possible results of the training intervention.

Chapter 5: An experimental study that builds on the methods used in Chapter 4 to determine whether a specialised training programme, that targets the shoulder girdle and hip extensors, can improve both sprint performance and ball speed in a group of youth field hockey players.

Chapter 6: The final chapter summarises all the findings from the previous chapters and the thesis as a whole. Key limitations and delimitations will be highlighted, what the findings mean for the practitioner and how might they apply them, what gaps still exist and therefore directions for future research and finally what the overarching conclusions are for the whole thesis.

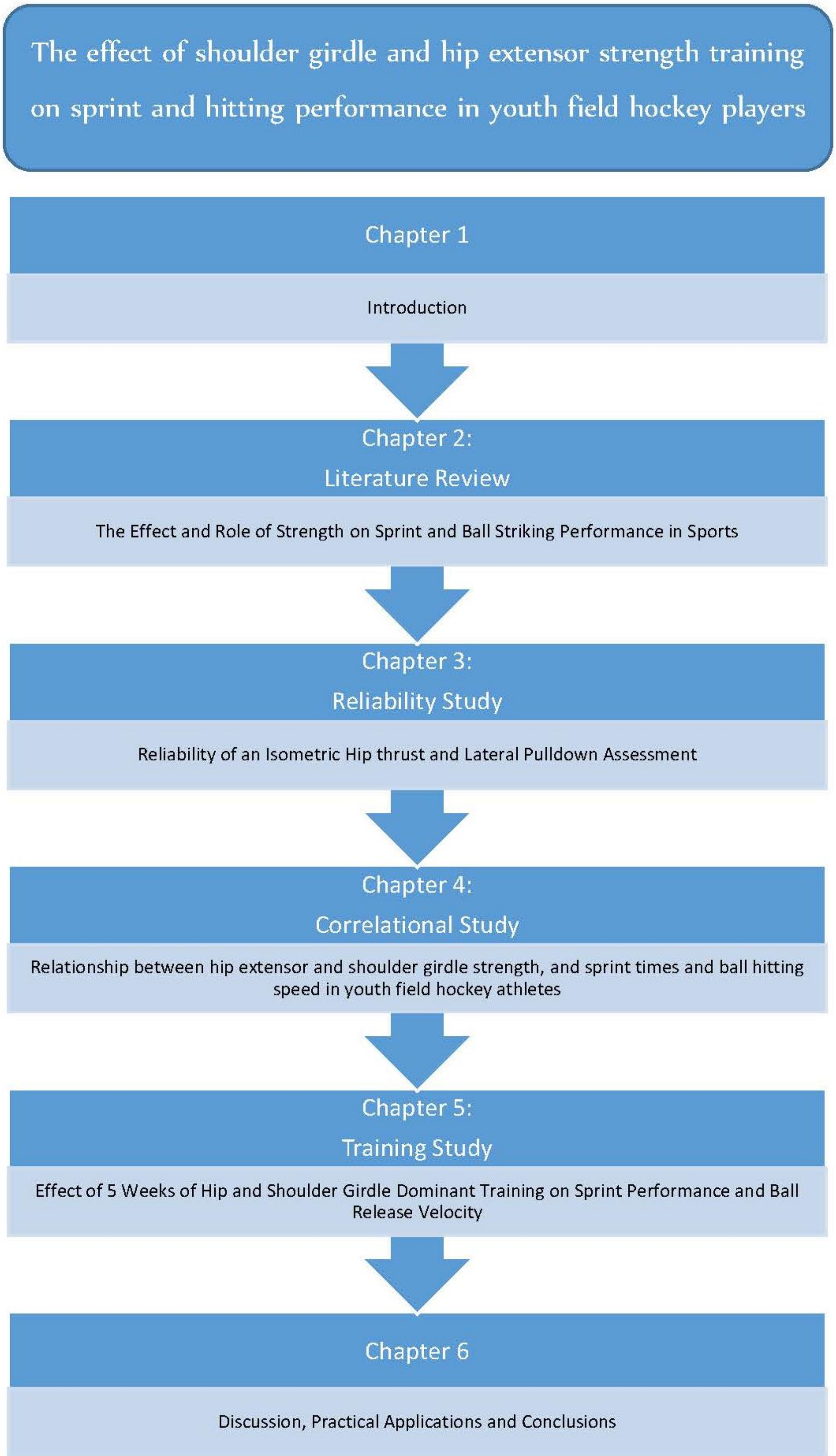

Figure 1. Thesis structure

Thesis Format

As the chapters in this thesis are formatted for publication, and thus written to be understood in separation from the thesis, there is some overlapping and repetition of themes throughout several sections of the chapters. In particular, the introductions and discussions of Chapters 3, 4 and 5 present similar information and themes to Chapter 2 surrounding the role of both the shoulder girdle and hip extensors in sprinting and ball striking, the relationship between these factors and lastly the effect of strength training on these performance measures. The methods used for assessing isometric shoulder girdle and hip extensor strength detailed in Chapter 3 are also used in Chapters 4 and 5. Lastly while Chapter 6 is not formatted for publication, it does draw on information from each chapter so as to synthesise all the findings for application to the field. Therefore as it acts as a summary and practical application of the thesis' overall findings some repetition exists between it and the previous chapters.

CHAPTER 2

Literature Review: The Effect and Role of Strength on Sprint and Ball Striking Performance in Sports

Abstract

Field hockey is one of the world's most popular sports, but there has been no research examining the relationship between strength and sport-specific performance measures, or the effect of strength training on these measures. A broader review of the literature, looking at other sports with similar requirements, revealed that there are significant relationships between sprinting and lower body strength (both isoinertial and isometric). Though these relationships have not been as well established in youth athletic populations, from the available literature it would seem that there is a significant relationship between lower body strength and sprint performance. Despite the upper body playing only a small, albeit vital, role in sprinting there is a lack of research exploring the relationship between upper body strength and sprint performance. The review also examined the relationship between upper and lower body strength and ball striking performance. In comparison to sprinting there is far less research on these relationships, with the majority of studies having been performed in golf and using adults. Though less research has been performed a greater number of exercises have been examined, with the available literature suggesting that there is a significant relationship between both upper and lower strength and ball striking performance. Two studies looked at isometric strength and found contrasting results, though the study with a considerably larger sample size reported significant correlations between the isometric mid-thigh pull and ball striking performance. As correlational studies can only establish the strength and significance of a relationship the review also explored the effect of strength training on performance markers. For sprinting it was found that in youth there is a small but significant causal relationship, with studies having looked at the effect of lower, but not upper, body strength training on sprint performance. For ball striking the majority of studies were performed again in golf using adults, with the results indicating that both lower and upper body strength training can improve ball striking performance. It is difficult to determine whether the results found in golf would be similar in other ball striking sports as differences do exist, however a study performed in tennis also found positive results. In conclusion with regards to sprinting while the relationship between lower body strength and sprint performance in youth has been fairly well established there is a definitive gap with regards to upper body strength. However, for ball striking performance while the relationship between both upper and lower body performance has explored, at least in golf, there is a lack of research in other sports and with youth athletes.

Introduction

As the topic of this review encompasses both sprint and ball striking performance in sports such as field hockey, the discussion naturally also concerns the proximal musculature of both the upper and lower limbs. As the functional link between the shoulder girdle and the hip girdle this chapter will start by offering a brief overview of the thoracolumbar fascia. Initially the anatomy of the thoracolumbar fascia will be examined, including how it physically connects the shoulder girdle and hip extensor musculature, followed by a brief exploration of its ability to transmit forces between the major muscles of the hip and shoulder girdle. The idea of force transmission between the shoulder girdle and hip extensors will then be used to analyse both sprinting and ball striking movements, including correlations with different exercises and the effects of strength training modalities on sprint and ball striking performance.

To establish a better understanding of the role of lower- and upper-limb muscles in both sprinting and ball striking sports EMG studies of these movements are reviewed. Studies using EMG not only give a general understanding of what muscles are employed during a movement but can, to a certain extent, provide insight into levels of muscle activation during a movement. These studies are only the first step though in understanding the importance of different muscles as, due to methodological issues, they need to be interpreted carefully. Therefore the next two sections, through the use of correlational studies, examine the relationship between the strength of this musculature, as measured through various exercises, and both sprinting and ball striking performance. While correlational studies can establish whether a significant relationship exists between various parameters and the strength of the relationship, correlation by itself does not imply causation. The final step in understanding the nature of this relationship, and establishing whether it is causal or not, is to perform a training intervention. In the following two subsections training studies that have examined the effect of strength training, when possible in particular those that have used shoulder girdle and hip extensor exercises, on both sprint and ball striking performance are reviewed.

In many instances there is a lack of studies featuring youth athlete participants. Relevant literature from adults will therefore be used to supplement what studies are available for youth. However, it should be noted that when only adult literature is available the results found not be entirely representative of a youth athlete's response. Due to a variety of factors, such as those relating to growth and maturation, research has demonstrated that youth athletes may show a somewhat different response to training in comparison to their adult counterparts. For instance, as motor skills are less developed and less stable in youth athletes, the relationship observed between performance and strength measures may not necessarily be as consistent. Lastly as this thesis is solely examining the role of strength and strength training, investigations of plyometrics or power development without a strength training component will not be included.

The thoracolumbar fascia

The thoracolumbar fascia is a large, roughly diamond shaped, area of connective tissue that consists of three layers. The anterior layer rises from the anterior surface of the lumbar transverse processes and covers the quadratus lumborum. The middle layer starts at the tip of the lumbar transverse processes and passes between the paraspinal muscles and the quadratus lumborum. Finally the posterior layer consists of two laminae the superficial lamina and the deep lamina. The superficial lamina derives from the aponeurosis of the latissimus dorsi and is part of a collective sheath of fascia that bridges from the first rib down to the xiphoid process anteriorly and from the cranial base to the sacrum posteriorly. The deep lamina extends from the spinous processes to the transverse processes. Cadaver studies note a physical connection between shoulder and hip girdle muscles, such as the latissimus dorsi and contralateral gluteus maximus, via the thoracolumbar fascia, as illustrated in figure 1 (Willard, Vleeming, Schuenke, Danneels, & Schleip, 2012). A study by Vleeming, Pool-Goudzwaard, Stoeckart, van Wingerden, and Snijders (1995) noted that when traction was applied to either the latissimus dorsi or gluteus maximus displacement occurred in the other muscle on the contralateral side. It was therefore concluded that these muscles mechanistically connect to transmit forces between lower limb, trunk, and upper limb via the thoracolumbar fascia.

Figure 2. The thoracolumbar fascia. A posterior view of a cadavers back, illustrating the attachments of the latissimus dorsi and gluteus maximus to the thoracolumbar fascia. Adapted from Willard et al. (2012).

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To date only one study has investigated force transmission between the latissimus dorsi and gluteus maximus in vivo (Carvalhais et al., 2013). Participants were placed in a prone position on an isokinetic dynamometer with an attachment to measure passive hip torque during medial rotation, permitting only 25-degrees of both medial and lateral rotation. Participants performed three repetitions for each of the three test conditions. In the first condition the upper limb rested passively at the side, whereas in the second condition passive latissimus dorsi tension was produced by the arm being positioned at 120° of flexion and the scapula elevated by a cable attached to the wrist. In the final condition participants actively contracted the latissimus dorsi to produce shoulder adduction and scapular depression. Baseline maximum voluntary MVIC and EMG testing established a threshold of 25% of MVIC for the active condition, allowing 10% variation but excluding trials that exceeded this. To ensure that muscles of the hip girdle were relaxed during each trial for each condition, EMG was recorded for selected muscles (including the gluteus maximus and gluteus medius). The authors observed that during the active condition the hip was moved from its resting position into lateral rotation and passive stiffness increased. These results supported the authors' hypothesis that force transmission between latissimus dorsi and gluteus maximus observed *in vitro* also occurs *in vivo*. Interestingly the EMG levels produced during active tensing (approximately 25% of MVIC) are lower than those observed in other activities, such as a lateral pulldown (60-80% of MVIC) (Andersen, Fimland, Wiik, Skoglund, & Saeterbakken, 2014) and a youth tennis players forehand shot (approximately 40% of MVIC) (Rogowski, Rouffet, Lambalot, Brosseau, & Hautier, 2011). As these levels exceed those reported by Carvalhais et al. (2013) it is likely that there would also be a stronger pull on the gluteus maximus and a more pronounced effect on the hip than reported.

The role of the shoulder girdle and hip extensors in locomotion

There is a paucity of research on the role of the upper extremities in sprinting. Early qualitative analysis suggested that the role of the arms was to balance the rotational action of the hips. However, some have also suggested that an aggressive backswing by the arms may increase stride length which is a key determinant in sprint performance (Mann & Herman, 1985). An early study by Mann and Herman (1985) that looked at the kinetics of sprinting using two-dimensional analysis showed that there was a minimal amount of muscular contribution by the elbow and shoulder joints, further reinforcing the idea that the role of the arms was merely to aid in balance.

In a later study of runners that used three-dimensional analysis, Hinrichs, Cavanagh, and Williams (1987) reported that the arms provided a small (5-10%) but important part of the total vertical impulse during the contact phase. This analysis concluded the arms assist in generating the vertical impulse that propels the body upward into the flight phase. Hinrichs et al. (1987) also described how as running speed increased the lift generated by the arms also increased. Prior to this study it had been suggested that the arms also contributed to drive (defined as the impulse resulting from the forward acceleration of the combined arms relative to the trunk). Whilst the results of Hinrichs et al. (1987) did not entirely support this, there was considerable variability and some subjects were able to generate positive drive from their arms during either the contact and/or propulsive phase. Hinrichs et al. (1987) noted that lift generated by the arms increased concomitantly with increases in running speed, therefore it could be that the amount of lift generated would continue to increase if the participants continued increasing their speed and began to sprint. Finally the authors also confirmed that the arms were able to stabilise the body's centre of mass and help avoid excessive side to side movement, thereby allowing the runner to maintain a more constant velocity.

During the acceleration phase of sprinting, or short sprints, the body has a pronounced forward lean. It has therefore been postulated that the usual vertical lift generated by the arms during upright running might contribute to horizontal propulsion during acceleration (Young, Benton, Duthie, & Pryor, 2001). Based on this premise the same authors suggested that the muscles that drive the arms, such as the latissimus dorsi and pectoralis major, might be of relative greater importance for athletes who perform short sprints rather than sprinters.

In sprinting the stride can be divided into two primary phases; the stance phase and the swing phase. The stance phase begins when the foot strikes the ground and finishes when the toe leaves the ground. The swing phase then begins when the toes leave the ground ('toe off') and concludes when the foot strikes the ground again. The hip extensors role is to propel the body forward by extending the hip after the reversal of the swing phase when the foot is in front of the body (Novacheck, 1998).

When Mann, Moran, and Dougherty (1986) compared EMG muscle activation patterns of various muscles across jogging, running and sprinting, they found that the gluteus maximus demonstrated greatest activity as the foot descended in the late part of the swing phase. The authors noted that, unlike the gluteus maximus, the hamstrings were active for similar amounts of time during both the late swing phase and early stance phase. As the hamstrings influence both the hip and knee joints it was found that they were active just prior to maximum hip flexion and shortly after the start of knee extension. It was proposed that through an eccentric action the hamstrings also help to restrain the hip joint as it approaches the end of flexion and regulates the rapid extension of the knee joint. Finally the period of hamstring activation during the stance phase was noted to be effected by the participants' speed, with it being active for longer during sprinting.

Further work by Novachek (1998) highlighted, by plotting joint power curves over increasing speeds, that the relative contribution from different muscles to power generation changed as speed increased with proximal muscles such as the hip extensors increasing during the second half of the swing phase and first half of the stance phase. By using gait data over a variety of speeds and musculoskeletal modelling Dorn, Schache, and Pandy (2012) observed that peak forces for the gluteus maximus and hamstrings doubled between the slowest and fastest speeds during the late swing phase. The authors also identified a causal relationship between the actions of the hip muscles (both flexors and extensors) and stride frequency. Using their model they were able to calculate that stride frequency was increased by increasing the forces generated by the gluteus maximus and hamstrings due to their significant contributions to the larger hip and knee joint accelerations observed at higher running speeds.

The role of the shoulder girdle and hip extensors in striking

To date no studies have looked at the role of either the shoulder girdle or hip extensors during shooting in field hockey. Therefore other ball striking sports such as baseball that have had EMG studies performed will be reviewed in this section. Though direct comparisons cannot be made between these sports, due to certain kinematic similarities they have been found to use similar muscles and recruitment patterns. These similarities may give some insight into the potential importance of certain muscles, as well as recruitment patterns, in field hockey.

Baseball

In a study of 25 male professional baseball players batting kinetics and kinematics Welch, Banks, Cook, and Draovitch (1995) described how a batter generates bat speed using a kinetic link - the basic idea being that the large base segments transfer momentum to smaller adjacent segments. A batter initiates a swing by using a clockwise rotation (right-handed batters) of the arm, shoulder and hips while simultaneously shifting the weight to the rear foot. This loading action has both a rotational and linear component. The rotational component has segments move around the axis of the trunk. Welch et al. (1995) noted that a key factor is the amount clockwise rotation by each segment. Excessive rotation interrupts a batters' ability to fully incorporate the trunk and upper extremity. The linear component is that of the batter shifting his weight onto the rear foot. This shift has the batter move his centre of pressure behind the centre of mass which in turn results in the body moving toward the direction of the centre of mass. When this is combined with the application of shear force by the rear foot (pushing the body forward), it drives the batter in a linear fashion towards the ball. As the batter's foot makes contact with the ground, the rotational and linear component begin to interact. When the foot touches down the application of shear forces by both feet produce a force couple at the hip segment which allows its counter-clockwise acceleration around the axis of the trunk. By aligning the centre of pressure with the centre of mass between both feet a significant shear force is able to be applied allowing for the force couple being applied to the hip segment to be increased. Although slightly different, the same principles have been found to occur in both golf (Milburn, 1982) and field hockey (Ibrahim, Faber, Kingma, & van Dieen, 2017; Kerr & Ness, 2006).

Electromyography studies of baseball batters seem to support the findings of Welch et al. (1995) and the proposition that force production originates from the lower limb and is transmitted via the sequential action of each segment through to the shoulders and upper limb. A study by Shaffer, Jobe, Pink, and Perry (1993) took EMG readings of various lower body muscles of 18 professional baseball players during batting. It was during the pre-swing phase, which started as the lead foot struck the ground and ended when the bat started to move forward, that the biceps femoris and gluteus maximus experienced their highest level of activity (154% ± 76 and 132% ± 53 MVIC respectively). The authors suggested that this was an indication of their role in power production. This is in line with Welch et al. (1995) suggestion of the hip segment exerting a large amount of force as it begins rotating towards the pitcher. As the players moved into the early swing phase, when the bat moved forward to being perpendicular with the ground, the muscle activity dropped but still remained relatively high with the biceps femoris registering 100% ± 71 MVIC and the gluteus maximus 125% ± 45 MVIC. From this point on the muscle activity dropped drastically in both the biceps femoris and gluteus maximus with the next phase of the swing registering only 57% ± 47 MVIC and 65% ± 37 MVIC respectively.

Only one other EMG study in baseball has looked at the hip extensors, specifically the biceps femoris and gluteus maximus (Reyes et al., 2011). The authors documented both similar and contrasting results to those of Shaffer et al. (1993). With both muscles experiencing their highest levels of activation in the same phase of the swing. However, the levels recorded were not the same with the biceps femoris experiencing 115%-120% MVIC and the gluteus maximus between 70%-80% MVIC. A possible reason for this could be due to discrepancies in the procedure used to attain MVIC, another is the experience level of the players used in the study with 11 of the 16 having only played at high school level. In the Welch et al. (1995) study they noted that if during the early phase of the swing the centre of mass moved onto the lead leg then force produced by the hip segment was reduced. Therefore, if the subjects where not as skilled or had not practiced for a few years the technique and effective force generation that results might be different. Whereas the results of the two EMG studies show that the biceps femoris activity does significantly decrease in the middle phase, they diverge over the gluteus maximus activation, with Reyes et al. (2011) study finding that it remains relatively unchanged. No other studies have looked at the activation of different hip muscles in baseball, therefore, more work needs to be done to establish the correct sequencing.

Reyes et al. (2011) also recorded EMG data for the latissimus dorsi showing that they peaked (90%-100% MVIC) in the middle part of the swing phase, marked from when the bat was perpendicular to the floor until it arrived in a position parallel to the floor, and then steadily dropped after. Although there is no other data to which this can be compared, this sequence would seem to follow Welch et al. (1995) idea of a kinetic link with force being transmitted from muscles lower in the body (biceps femoris) to those in the trunk/upper body (latissimus dorsi).

Tennis

Tennis is another ball striking sport, with both the forehand and backhand strokes sharing similar movement patterns with baseball, albeit the forehand stroke particularly is most often executed one-handed. Ryu, McCormick, Jobe, Moynes, and Antonelli (1988) looked at muscle activation levels of the shoulder for both the forehand and backhand stroke in a group of six male Division-II intercollegiate tennis players. For both strokes the latissimus dorsi was found to be the most active during the acceleration phase. During the backhand stroke players registered almost double the activation as observed during the forehand (45% and 24% of manual muscle testing (MMT) respectively). It would seem logical for the backhand to have a higher latissimus dorsi reading than the forehand as the movement requires the lead hand to be in a reverse position which, when performed with a double hand grip, bears a resemblance to batting in baseball. It is worth noting that the latissimus dorsi reached their peak activation level in the acceleration phase which is similar in description (weight transfer to the front foot accompanied by forward racquet movement ending in ball contact) to that of Reyes et al. (2011) middle swing phase.

Rogowski et al. (2011) used EMG to look at the muscle activation levels of 29 youth (age = 9-14 years) national-level tennis players during two forehand shots (flat and topspin). When the group was divided based on skill level, defined as ability to increase racquet speed between the two different shots, it was revealed that the less experienced players had lower latissimus activation than the more experienced players (20%-30% and 40%-50% MVIC respectively). The more experienced players achieved even higher latissimus dorsi activation levels than the players in Ryu et al. (1988) study despite them being older (age= 18-21 years). One potential reason for this is that despite the age difference the younger players were classified as being more experienced hence more developed in terms of technique. Another likely explanation for the different findings is that in Ryu et al. (1988) study the forehand stroke was performed with a single hand grip, whereas in the Rogowski study there was a split among players with some using a single hand grip and others a double. Unfortunately the authors did not specify, or differentiate, between the findings from single- versus double-handed forehand players, so it is not possible to confirm the extent to which this was a factor.

Finally, a study by Rota et al. (2012) of 21 male advanced tennis players looked at the changes in trunk and upper-limb musculature activation as stroke velocity increased during a forehand shot.

The authors discovered that there was a linear relationship between ball velocity and latissimus dorsi activation level indicating that as players tried went from submaximal strokes to maximal strokes players utilised their latissimus dorsi more. These results are in agreement with the findings of Rogowski et al (2011) who reported that the experienced group had higher latissimus dorsi activation also had higher racket velocities. To date no studies have looked at lower body muscle EMG in tennis players, therefore it is not possible to know whether they are comparable in intensity or firing pattern to baseball.

Golf

Golf is one of the few other ball striking sports that has had EMG studies performed to discover what muscles are used during performance. The plane of the golf swing is also somewhat similar to the drive stroke in field hockey. One of the earliest studies was performed by Jobe, Moynes, and Antonelli (1986) and recorded EMG for six rotator cuff muscles of seven right-handed male professional golfers. Original data from the study showed that the latissimus dorsi started to fire at moderate level during the forward swing which is from the end of the back swing until the club is horizontal. However, it was during the acceleration phase that followed, when the club travelled from horizontal until ball contact, that the latissimus dorsi reached peaked activation with the data suggesting that it was more than 100% MMT. The authors concluded that it was the latissimus dorsi, along with the pectoralis major and subscapularis, which provided the power to this phase and ultimately drove the club to its maximum velocity.

Jobe, Perry, and Pink (1989) would later combine the data from the previous study with EMG data of seven professional female golfers. The author's believed that the extra data combined with new more advanced analysis techniques would provide a better insight into muscle recruitment during the swing and whether this differed between male and female players. As the activation levels did not differ according to gender the authors combined the data and reported that not only were the activation levels lower for the latissimus dorsi but they peaked in a different phase of the swing. The highest activity levels for the latissimus dorsi were found to occur during the forward swing phase (right = 50% ± 38 left = 46% ± 25 MMT) with activation levels not changing significantly during the acceleration phase (right = 47% ± 44 left = 31% ± 28 MMT) as previously reported. They concluded that the power in the shoulder for the drive was predominantly coming from the latissimus dorsi and pectoralis major, with the latissimus dorsi contributing its power earlier on due to its role as an internal rotator of the humerus.

Currently only two studies have examined muscle activation patterns in the lower body during a golf swing. Bechler, Jobe, Pink, Perry, and Ruwe (1995) measured muscle activation in the hip and knee musculature for 13 male and three female competitive golfers. In their analysis they reported that the most active phase for the rear leg was during the forward swing phase when the rear hip begins to extend creating pelvic rotation. The upper and lower gluteal muscles and the biceps femoris were the three most powerful muscles in this phase with the upper gluteal muscles reaching 100% ± 55 MMT. The collective action of these muscles serve to push the trail hip in the direction of the swing and initiate pelvic rotation. The authors suggested that the reason for such high levels of gluteus maximus activation in the players studied was that it pushed the previously flexed hip into the shot. The authors reported that the acceleration phase that followed was characterised by a change in activity from the trail leg to the lead leg with both the gluteus maximus muscles and the biceps femoris reaching their peak activity. It was their belief that during this phase the gluteus maximus of the lead leg would be in a position to assist with hip extension and pelvic rotation whereas the biceps femoris would be able to maintain a flexed knee allowing for the transfer of power from the pelvis to the trunk and arms.

Watkins, Uppal, Perry, Pink, and Dinsay (1996) performed a similar study using 13 professional male golfers and recording EMG for select trunk musculature that included the gluteus maximus but not the biceps femoris. The authors detailed similar findings to the previous study with the trail leg gluteus maximus producing a relatively low baseline throughout the movement apart from in the forward swing phase when in spiked (84% MMT). The left gluteus maximus activity increased as the swing progressed with it reaching its maximum activation during the acceleration phase and then declining.

Although direct comparisons cannot be made between these three sports it is interesting to note that the phase of the movement when the latissimus dorsi, gluteus maximus and biceps femoris are activated the most seems to be similar in description. Therefore these findings would seem to suggest that in striking sports which involves a rotational element, both the hip extensors (primarily the gluteus maximus and biceps femoris) and the shoulder girdle (primarily the latissimus dorsi) play an important role in force generation and delivery of impulse at contact.

Relationship between strength and sprint performance

There is a paucity of studies investigating the relationship between upper body strength and sprint performance. Only one study to date examined the relationship between an upper body strength measure and sprint performance, with Luhtanen and Komi (1978) reporting significant correlations between bench press power and 36.6-m sprint performance.

Studies examining the relationship between lower body strength and sprint performance can be divided, into two broad categories based on the form of assessment used. The first category comprises studies that employed isoinertial strength testing, whereby a free weights exercise is used and participants are required to complete a designated number repetitions with the highest load they are able to handle. While most studies in this category require the participant to achieve their true one repetition maximum (1RM), that is the maximum load they can handle for a single repetition, some employ a three or five repetition maximum and then use a an equation to predict their 1RM. As will be discussed later the most common exercise used in the literature is the barbell back squat. The second category are those studies that use isometric strength testing, with the most common exercise used being the isometric mid-thigh pull (IMTP). The literature that exists will be briefly reviewed with studies being grouped based on whether the population used was adult or youth and then further sub-divided into the two assessment categories.

Isoinertial strength testing has been performed with a range of adult populations, including both non-professional and professional athletes and in a variety of sports including rugby, American football and soccer. In these studies the highest correlations were observed when strength was expressed relative to bodyweight, rather than absolute strength. The only study to find high correlations with absolute strength is a study by Peterson, Alvar, and Rhea (2006) who used a mixed sample of male and female university level athletes from a range of sports. The authors reported that when the data from both sexes was combined very large significant correlations were found between back squat 1RM and 20-m and 30-m sprint performance ($r=0.820$ and 0.854, $p\leq0.05$ respectively). However, it is interesting to note that for both these distances relative 1RM (1RM divided by bodyweight) still had a stronger correlation ($r= 0.876$ and 0.881, $p\leq0.05$). In addition, when the data was grouped by gender, no significant correlations existed across any distance for men when using absolute 1RM, whereas in women the correlations reported became weaker.

Across all the studies the highest correlation between lower body strength and speed was recorded by Wisloff, Castagna, Helgerud, Jones, and Hoff (2004). This investigation assessed the relationship between 10 and 30-m sprint performance and squat strength in a team of elite soccer players. The authors found that 10-m performance had almost a perfect correlation with squat strength ($r=0.94$, $p=\leq0.001$). However, unlike the majority of studies performed the authors used allometric scaling, where the amount of weight squatted was divided by bodyweight and then raised to the power of 0.75. The authors proposed that strength does not increase in direct proportion to body mass and that this method allowed for larger athletes scores not to be underestimated and smaller athletes to be overestimated.

Finally, a study Swinton, Lloyd, Keogh, Agouris, and Stewart (2014) is worthy of mention, as they used both a back squat and deadlift in their assessment of rugby players as well as allometric scaling (1RM/bodyweight(kg)$^{0.67}$). Interestingly the authors found that not only was there little difference between the back squat and deadlift correlations for either 5, 10 or 30-m sprint performance but also that they ranged from large to very large with r= 0.58 for 5-m and r= 0.82 for 30-m. The collective results of the studies indicates that there is quite a strong relationship between allometrically scaled relative strength in the back squat and sprint performance. However, further research is needed to determine the best way of calculating strength scores, relative or dimensionless, when determining its relationship to sprint performance.

Similar to the studies cited above, isometric strength testing has also been used with participants from a range of sports and competitive levels. As mentioned previously the most common isometric assessment method is the IMTP. The two notable exceptions are a study by Tillin, Pain, and Folland (2013) who utilised an isometric back squat, and an investigation by Cunha et al. (2007) which employed an isometric leg press. Across the studies moderate to very large (r= 0.37–0.716) correlations were found between both absolute and relative force and sprint performance across a range of distances (5-m to 60-m).

A statistical factor that appeared to affect the size of the correlation in some studies was the sampling window employed for the isometric force measure. For instance, West et al. (2011) noted that in a group of 39 professional rugby league players the relationship between absolute and relative force, measured using IMTP, and 10-m sprint time increased when values were sampled at 100ms. When using the sampling window of 100ms peak force went from having no significant correlation to having a significant correlation (r= -0.54 p=≤0.01) and relative force increased the strength of its correlation (r= -0.37 to -0.68). However, while both West et al. (2011) and Tillin et al. (2013) found differing levels of significance in the relationships when different sampling windows were used, studies do not always report this finding. Both Wang et al. (2016) and Jonathan, Russell, Shearer, Cook, and Kilduff (2017b) reported that employing different sampling windows at a range of times (30-250ms) did not affect the level of correlation that resulted.

A study by Thomas, Comfort, Chiang, and Jones (2015) of university soccer and rugby players was unique in its approach as rather than use peak or relative force as the other studies they used impulse. There are strong arguments that impulse is far more relevant to jumping and acceleration performance than average force or peak force metrics, based upon studies in the literature and Newtonian physics. Relative net impulse has been identified as the major determinant of performance in jump height in vertical jump studies (Kirby, McBride, Haines, & Dayne, 2011) and acceleration performance in sprint running studies (Hunter et al., 2005). Thomas et al. (2015) reported that while significant correlations were found between peak force and 5-m ($r = -0.57$, $p = \leq 0.05$) and 20-m ($r = -0.69$, $p = \leq 0.01$) performance, these increased when impulse was used with either a 100ms ($r = -0.71$ and $r = -0.75$, $p = \leq 0.01$) or 300ms ($r = -0.74$ and $r = -0.78$, $p = \leq 0.01$) sampling window. Given the importance of impulse and the fact that the study found the highest correlations for an isometric exercise, it would be worthwhile for future studies using isometrics to also examine correlations for impulse, rather than simply reporting peak and relative force.

Far fewer studies have been carried out in youth athletes than in their adult counterparts. Based on the available studies that employed isoinertial assessments the results seem to be similar, with relative strength having in general a higher correlation to sprint performance than absolute strength. In a study of youth (age= 17.2±0.6yr) soccer players Comfort, Stewart, Bloom, and Clarkson (2014) found mixed results, with absolute 1RM in the back squat having a larger correlation to 5-m sprint time ($r = -0.596$) than relative 1RM ($r = -0.519$). The opposite was then found to be true with 10-m sprint time, whereby relative 1RM had a larger correlation ($r = -0.672$) than absolute strength ($r = -0.645$). Kirkpatrick and Comfort (2013) also used absolute and relative 1RM when examining the relationship between squat strength and sprint performance (10-m, 20-m and 30-m) in elite junior rugby league players. While the authors reported a smaller correlation between relative strength and sprint performance for 10-m sprint time ($r = -0.45$ $p \leq 0.01$) than Comfort et al. (2014) (with similar correlations found for the other distances), of more interest is that they found no correlation between absolute strength and sprint time across any of the distances.

In the youth literature only two studies have looked at the relationship between isometric assessments, both of which used the IMTP, and sprint performance. In a group of 18 male academy cricket players (age= 17.1±0.7yr) Thomas, Dos'Santos, Comfort, and Jones (2016) found no significant relationship between peak force relative to body mass and sprint performance over 5, 10 or 20-m. Thomas, Comfort, Jones, and Dos'Santos (2017) also used the IMTP to examine the relationship between peak force relative to body mass and both 5 and 10-m sprint time but in a group of academy netball players (age= 16.1±1.2yr). Unlike Thomas et al. (2016) however, the authors did find a relationship between peak force relative to body mass and 5-m sprint time ($r = -0.49$, $p \leq 0.05$), although they reported no significant relationship with 10-m sprint time.

It is difficult to draw any definitive conclusions on the relationship between lower body strength and sprint performance in adults due to the limited number of studies, which vary depending on their employment of either isoinertial or isometric strength assessments. The type of strength assessment, and what exercise was used, will clearly have a bearing on the results reported. The overall picture is also somewhat dependent upon how the data was analysed, particularly whether the study reported absolute strength, relative strength or allometrically scaled strength. From the evidence available it would seem that whether using an isoinertial or isometric assessment relative, or bodyweight-scaled, strength has a stronger relationship with sprint performance when the free weight back squat or IMTP are used. With regards to isometric assessments it would seem that using sampling windows also increases the size of the correlation. Finally, there is a strong theoretical argument that impulse might have the best relationship with sprint performance, which is supported by empirical evidence, albeit more studies are needed. Though there are even fewer studies with youth athletes it would seem that, in isoinertial studies at least, there is also a stronger relationship between relative strength and sprint performance than absolute strength. As there are only two studies that have looked at isometric strength, both with differing results, more work is needed to establish whether there is a significant relationship between these parameters in youth athletes.

Relationship between strength and striking performance

Relatively few studies have looked at the relationship between strength and ball striking performance. The majority of these investigations feature the sport of golf, and employ adult participants. The research interest in strength parameters for ball striking in golf is understandable given that club head speed (CHS) is strongly linked to critical factors for the sport, specifically ball velocity and therefore distance. This section will firstly examine the reported relationships between performance and upper body strength, before then moving onto the respective studies investigating lower body strength.

Thompson (2002) examined the relationship between club head speed and various upper body strength measures in a cohort of male golfers (n= 31, age 65.4 ± 6.7yr). The study assessed strength for a range of pushing and pulling movements in different planes, employing10RM testing with a selection of resistance machine exercises. The author reported that a range of exercises including shoulder press (r= 0.49, p=0.005) and chest press (r= 0.44, p=0.014) had large positive correlation to CHS. Equally, two of the highest correlations were for the lateral pulldown (r= 0.58, p=0.001) and seated row (r= 0.45, p=0.01) with the lateral pulldown having the highest correlation in the study.

A later study by Hellström (2008) investigated the relationship between two upper body strength measures (pull-ups and parallel dips) and CHS in a group of 33 elite Swedish golfers. Interestingly although strength in the parallel dips correlated well with CHS ($r= 0.35$, $p=\leq 0.05$) no statistical correlation between pull-up strength (pronated grip) and CHS was observed. Wells, Elmi, and Thomas (2009) also used pull-ups (supinated grip), in a study of 24 golfers from the Canadian national golf team, though they looked at the relationship between the number performed in 60 seconds and ball speed when a driver or 5-iron was used. Unlike Hellström (2008) the authors found large positive correlations between the number of pull-ups performed and ball speed with both a driver ($r= 0.8$, $p=\leq 0.0001$) and 5-iron ($r= 0.78$, $p=\leq 0.0001$). In the same study the authors also recorded the number of push-ups performed in 60 seconds which, although still having large correlations to speeds with both clubs ($r= 0.66$, $r= 0.57$, $p=\leq 0.0001$ respectively), were smaller than those found in the pull-ups.

There have been a small number of investigations of upper body strength and implement speed in sports other than golf. One study of 18 elite cricket players (Taliep, Prim, & Gray, 2010) observed that 1RM in the bench press correlated with batted ball distance ($r= 0.63$ $p=\leq 0.0052$). Similar results were also reported when swing speed was measured in 30 high school baseball batters ($r= 0.588$, $p=\leq 0.05$) (Miyaguchi & Demura, 2012). Apart from the results found by Hellström (2008) it would seem that there is a relationship between the strength of shoulder girdle muscles, especially the latissimus dorsi and pectoralis major, and sport specific performance parameters such as CHS and ball distance. These results would also seem to be in agreement with the findings of EMG studies suggesting the importance of the shoulder girdle muscles in striking sports. However, due to the limited studies performed more work is needed where similar exercises are used in a range of sports and with participants of different ages and levels.

To date no study that has looked at the relationship between performance in a ball striking sport and a measure of lower body strength has used a hip extensor dominant exercise. Therefore the literature comprises studies using general lower body strength exercises. The Thompson (2002) study of recreational golfers cited previously also had the participants perform a 10RM leg press. As with the upper body strength measure, leg press 10RM strength scores reported a statistically significant correlation to CHS ($r= 0.49$, $p=\leq 0.005$). When Keogh et al. (2009) investigated the relationship between maximum squat strength (1RM in hack squat machine) and CHS in a group of 20 golfers (10 low handicap and 10 high handicap). Once again this study reported a statistically significant correlation between 1-RM machine hack squat strength scores and CHS ($r= 0.533$, $p=\leq 0.05$) with the authors noting no statistical difference between the two groups mean strength. Similar to Keogh et al. (2009), Hellström (2008) also observed a slightly higher correlation (r= 0.54, p=≤0.01) between lower body strength, this time using a barbell squat 1RM, than Thompson (2002).

One study that featured the sport of baseball reported different findings. Fry et al. (2011) investigated male players from a NCAA Division 1 baseball team, and found no significant correlation between back squat 1RM and ball velocity. This might be explained by the relative level of strength training history customarily found in baseball versus golf. We might speculate that the base level of strength of the baseball players studied was above the required threshold level, so that any differences between players were not sufficient to differentiate performance. The plane of the swing in baseball in also different to golf, specifically more horizontally oriented, which might also have a bearing on the relative involvement of lower body force generation during ball striking.

Along with these isoinertial studies, two isometric studies have been performed using the IMTP. In a study of 12 recreational golfers Leary et al. (2012) found there to be no statistically significant correlation between IMTP and CHS. That said, the authors noted that allometrically scaled force at 150ms did approach statistical significance (r= 0.47 p=0.07). In comparison, Loock, Grace, and Semple (2013) reported contrasting results when in a study of 101 recreational golfers (age= 17 - 71yr), who had no resistance training, they found that IMTP had a significant correlation to both driver (r= 0.558 p=0.011) and iron (r= 0.597, p=≤0.000) CHS. Loock et al. (2013) study is of particular interest due to the large sample, age range and the fact that they had no prior resistance training experience.

Once again, some caution is necessary in drawing conclusions, however based on the limited number of studies have been performed, with various methods and populations having been used, it would seem that there is a significant positive relationship between lower body strength and CHS, and therefore ball velocity (and ultimately distance). Further research needs to be done to determine whether this relationship exists in other sports and if so are higher correlations found for isoinertial or isometric assessments. Possibly the more pressing need is for research to establish whether there is a significant relationship between lower body strength, regardless of assessment type, and youth athletes considering the absence of data.

Effect of strength training on sprint performance in youth

Many studies have looked at the effect of strength on sprint performance in both adult and youth/adolescent populations. In the past year two systematic reviews and meta-analyses of the literature have been published relating to this topic. Therefore this section will highlight the findings of these reviews, and then discuss in more depth a handful of papers that are considered key to this thesis.

The review by Lesinski, Prieske, and Granacher (2016) attempted to quantify the effects of age, sex, sport and resistance training on physical performance in youth athletes. The authors also wanted to characterise a dose-response relationship of resistance training parameters that could maximise gains in physical performance. A between-subject standardised mean differences was employed (SMD=(mean post-value intervention group−mean post-value control group)/pooled standard deviation) to determine the effectiveness of resistance training on different measures of physical performance. In this way, the authors also sought to establish dose-relationships of resistance training for youth athletes. If more than one intervention group was available then a weighted mean was calculated for the SMD's (SMD_{wm}) and was interpreted using a modified scale for magnitude of effect sizes in strength training research. The author's search criteria resulted in them analysing 43 studies, with results revealing that resistance training had a moderate effect on muscle strength (SMD_{wm}=1.09) and a small effect on both linear sport-specific (e.g. throwing, hitting and/or kicking velocities) and sprint performance (SMD_{wm}=0.75 and 0.58 respectively). The analysis of the collective results also seemed to suggest that neither chronological nor biological age had a statistical effect on physical performance. That said, larger effects of resistance training on measures of sport-specific performance were found in adolescents (SMD_{wm}=1.03) than in children (SMD_{wm}=0.5).

Various sub-group analyses were also carried out in the review by Lesinski et al (2016), with two being of particular interest to the present thesis. The first indicated that resistance training produced significantly larger effects ($p=\leq 0.05$) on measures of sport-specific performance in girls (SMD_{wm}=1.81) in comparison to boys (SMD_{wm}=0.72). It should be noted however that only five all female youth studies were available for comparison. The second subgroup analysis found that different types of resistance training were significantly better at increasing strength ($p=\leq 0.001$) and sport-specific performance ($p=\leq 0.05$). Specifically, studies employing free weight strength training reported the largest effect on strength (SMD_{wm}=2.97), whereas complex training appeared to have the greatest transfer to sport-specific performance (SMD_{wm}=1.85). No statistical difference was found between the ability of the different resistance training types in improving sprint performance. The authors suggested that this might be due to its complex nature and variety of determinants contributing to performance.

A second meta-analysis by Behm et al. (2017) compared the effectiveness of strength and power training (e.g. plyometrics, Olympic weightlifting movements) on improving surrogate measures of muscle strength, power and speed in children and adolescents. Using their search criteria

107 studies were taken forward into their analysis in which they utilised SMD's but not SMD_{wm}. This review also employed a different magnitude of effect scale for interpreting the results. The authors found that strength training, rather than power training, tended to provide better sprint time results with strength training providing moderate (SMD=0.7) vs. small effects (SMD=0.47) in children and small (SMD=0.36) vs. trivial (SMD=0.13) in adolescents. The authors suggested that a potential reason for strength training providing better improvements lies in its ability to increase both concentric and eccentric strength components, which is needed to take advantage of the stretch-shorten cycle in sprinting where as plyometrics does not.

When the data was collectively analysed to look at the difference between the results in trained vs. untrained participants, it was found that untrained participants experienced a moderate (SMD=0.57) increase in sprint performance when using strength training, while power training provided a large (SMD=1.19) improvement. In trained participants the effect was found to be larger for strength training than power training however, for both the effect was only small (SMD=0.45 and 0.32 respectively). As highlighted by the authors, one needs to be careful when interpreting the robustness of these results due to the difference in the number of measurements available for both strength and power training (groups in each study). For both strength and power training in untrained youth participants there were only three measures whereas there were 11 and 30 for strength and power training respectively in the trained participants. With regards to lower body strength there were only four studies that looked at the effects of power training and so no clear result could be drawn. However, strength training seemed to have a large effect regardless of whether the participants were child or adolescent (SMD=1.39 vs. 0.88) or if they were untrained or previously trained (SMD=1.08 vs. 1.23).

Each of the two reviews discussed offer different insights due to the themes they used in their analysis. Overall it would seem that free weight strength training can be used to successfully increase strength in the youth athlete population, with already trained athletes experiencing greater effects than their untrained counterparts. For improving sprint performance lower body strength training seems to have a moderate effect on untrained and child populations, while only small effects on trained and adolescent populations. Finally, the findings reported seem to indicate that resistance training has a larger effect on sport-specific performance measures in adolescent rather than child (or prepubescent) athletic populations.

When looking at the effect of lower body strength training on sprint performance the majority of studies have used a squat movement, commonly a free weight squat to a depth of 90-degrees is used, albeit other exercises have been employed in some studies. Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, and Patikas (2005) investigated the effect of a combined training programme, which included resistance training and speed training in the same session, on sprint performance. Two groups of soccer players were used in the study, with the first receiving the combined training (n=12 age=17 ± 1.1 yr) while the second received only strength training (n=11 age=17.1 ± 1.1 yr). Training was performed three times a week with the strength training component involving 90° back squats, single leg step-ups and hamstring curls, while the sprint training involved 30-m sprints performed afterwards. After the nine week intervention the authors found that both groups strength increased across all three exercises and that there was no statistical difference between the two groups improvement. However, only the combined training group experienced significant improvements in 30-m sprint performance (Δ =-3.46%, p=≤0.01). This study would seem to highlight the importance of having athletes, specifically youth athletes in this study, perform sprint training, or sport-specific training that requires sprinting, during the intervention period. These findings seem to support an earlier assertion that strength training alone is not optimal for improving sprint performance (Delecluse, 1997).

Using a cohort of elite level professional soccer players (n=17 age= 18.3 ± 1.2 yr), with experience in resistance training but not high-intensity training, Styles, Matthews, and Comfort (2016) examined the effect of a six week high-intensity (85-90% of 1RM) squat programme on sprint performance. As well as the players performing 90° back squats they also performed Romanian deadlifts and Nordic lowers. The authors reported that the participants made small but significant (p=≤0.001) increases across all the distances measured (5, 10 and 20-m) and that there was a large correlation between percent change in squat 1RM and 5, 10 and 20-m performance. In this study participants were required to perform a 1RM Romanian deadlift (for programming purposes). As a commentary on this study, it would have been interesting for the authors to have performed a correlational analysis between 1RM Romanian deadlift scores and sprint performance due to the previously mentioned importance of the hip extensors in sprinting. Such an analysis might have also allowed for the authors to have evaluated the relative strength of relationship and indicate the relative contribution to the improvement in sprint performance. Lastly a potential reason for the improvement seen in sprint performance being only small, was due to the study being conducted during the participant's in-season and therefore soccer training and matches were also being conducted throughout the intervention period.

Hip Thrust

An exercise that has become increasingly popular among strength and conditioning practitioners is the barbell hip thrust. The hip thrust is a loaded bridging exercise that, when compared with a free weight back squat, was found via EMG to have greater mean and peak activation of the gluteus maximus (upper and lower) and biceps femoris (Contreras, Vigotsky, Schoenfeld, Beardsley, & Cronin, 2015). To look at the effects of six weeks hip thrust training on 10 and 20-m sprint performance Contreras et al. (2016) used a cohort of rugby players and rowers from an athlete development program. The participants were divided into two groups with one receiving hip thrust only training (n=14 age= 15.49 ± 1.16 yr) and the other front squat only training (n=14 age= 15.48 ± 0.74 yr). At the end of the study the authors observed that the hip thrust group experienced possible moderate beneficial effects for their 10-m sprint performance (ES= 0.55) and very likely large beneficial effects for the 20-m sprint performance (ES= 1.14). The front squat group however, were found to have experienced unlikely small beneficial effects in their 10-m and 20-m sprint time (ES= -0.02 and 0.19 respectively).

A similar study was later conducted by Bishop et al. (2017) who examined the effects of an eight week barbell hip thrust strength training programme on sprint performance. The authors used 21 collegiate athletes (age= 27.36 ± 3.17 yr) who were then randomised into a hip thrust (n=11) and control group (n=10). Unlike the previous study by Contreras et al. (2016) all participants had at least 1 year's resistance training experience including the use of the hip thrust. Similar to the prior study the participants were only allowed to use the hip thrust during the intervention period. When the authors analysed the post-intervention data they discovered that there were no meaningful improvements in either sprint performance across any of the distances (40-m with 10-m splits) or the overall 40-m. With such a disparity in results there is presently no clear evidence as to the hip thrusts efficacy in improving sprint performance more research is needed.

Unlike in adults where it has been reported that there is a very large correlation between squat strength improvement and sprint performance improvement (Seitz et al., 2014) the same does not seem to be true for youth populations. In youth populations it would seem that the effect of lower body strength training on sprint performance seems to vary based on maturation (e.g. child vs. adolescent) and level of training experience (e.g. trained vs. untrained). The majority of studies that have looked at improving sprint performance through increases in lower body strength have tended to utilise the back squat as one of their exercises. Whilst numerous studies have looked at using only the back squat to improve sprint performance few have examined the sole use of other lower body exercises. Therefore to determine the effectiveness of commonly used lower body exercises at improving sprint performance more studies like the ones by Contreras et al. (2016) and Bishop et al. (2017) need to be performed in both adult and youth populations.

Effect of strength training on ball striking performance

Currently there is a lack of studies looking at the effect of strength training on ball striking performance in youth athlete populations. Therefore this section will review the adult literature. It should be noted that while adult literature does exist it is limited by not only the number of studies but by the variety of sports, with the majority having been performed using golfing populations.

An early study by Hetu, Christie, and Faigenbaum (1998) looked to evaluate the effects of an eight week conditioning programme on measures of physical fitness in a mixed sex cohort of older recreational golfers (m=12 f=5 age=52.4 ± 6.7 yr). A secondary purpose was also to determine whether a conditioning programme was able to improve CHS. The participants trained twice a week using a full body workout that utilised a mixture of free weight and exercise machines including lateral pulldowns, dumbbell squat and dumbbell presses. At the end of the intervention period the authors found that the participants had not only increased measures of strength (Chest press=+14.2% p=0.0008 and Leg extension=+18.1% p=≤ 0.0001) but also CHS (Δ= 6.3% p= 0.0003). A limiting factor of this study was that there was no control group and so it was not possible to determine whether the improvements seen would have occurred regardless of participation in the study.

In a later study, Thompson and Osness (2004) followed on from the work of Hetu et al. (1998) by investigating whether a conditioning programme would elicit greater improvements in CHS for older male recreational golfers (age=64.8 ± 6.1 yr) in comparison to no conditioning. The intervention lasted eight weeks with the experimental group training three times a week and using a full body workout that utilised weight machines including a seated row, lateral pulldown and leg press. After analysing the data the authors reported significant strength increases for the experimental groups lateral pulldown, seated row and leg press 10RM (%Δ=21.3, 36.9 and 41.1 respectively) but not for the control groups. Concomitant significant increases were also observed for CHS in the intervention group but not for the control group (%Δ=2.47 vs. 0.63). While these findings would seem to suggest that strength training does increase CHS, it should be noted that both of these studies also had the participants perform a golf specific flexibility programme which could have had an impact on the results. Thompson and Osness (2004) also had the intervention group perform a golf specific exercise that involved swinging a 1.3 kg weighted club. This could have had a significant effect on their performance as will be shown in the results of the following studies.

Using a cohort recreational golfers considered to be of very good standard (handicap (HCP) = 5.5±3.7) Fletcher and Hartwell (2004) investigated the effects of a combined weights and plyometric training programme on golf drive performance. Like the other two studies the intervention period lasted eight weeks and involved the participants training twice per week using exercises such as the back squat, single arm row, lunge. Unlike the other two studies though the authors also had the participants perform both a seated and standing medicine ball throw. At the end of the intervention the authors found that while the control group experienced no significant increase in their CHS the experimental group did (Δ = 1.5% p=≤0.05). The authors contended that the training programme was successful due to the utilisation of both strength and plyometric training. Whilst not assessed in the study the authors also postulated the likely mechanisms, whereby the strength training increased force output and enhanced motor unit recruitment, whereas they suggested the plyometric exercises increased power output while mimicking the pre-stretch experienced during the back swing therefore being more sport specific.

Doan, Newton, Kwon, and Kraemer (2006) performed a similar study in a more elite population of golfers. Both male and female collegiate golfers were recruited (m=10 f=6 age = 19.3± 1.5 yr) but participation was restricted to those considered 'elite' with the men having a handicap of 0 and the women 5-10. The intervention lasted 11 weeks and required the participants to attend three strength training sessions a week where they performed both traditional free weight exercises such as step ups, dumbbell rows and lunges as well as seated and standing medicine ball throws. The authors reported that not only did the participants increase strength measures such as the lateral pulldown (Δ =12.61% p=≤ 0.000) and squat 1RM (Δ =13.27% p=≤ 0.000) but also CHS (Δ =1.62% p=0.029). Medicine ball throw velocity, which was measured both pre and post intervention, was also found to be significantly correlated to CHS (r = 0.86 p=≤0.05). The correlations stated were higher than any of those previously mentioned in this review and therefore might indicate why explosive medicine ball exercises had such an effect on CHS.

Lamberth et al. (2013) sought to explore the effect of a combined traditional and functional strength training programme on CHS in a cohort of highly skilled male golfers (n=10, age=21.4±2.3 yr, HCP=≤8). The intervention lasted six weeks and involved the participants in the experimental group performing two training sessions a week using exercises such as leg press, reverse lunge, lateral pulldown and cable wood chop. The authors found that at the end of the intervention period there was no significant change in the experimental or the control groups CHS. A possible reason that the authors pointed to was the use of a small sample size. However, given the results of the previous studies, two other possibilities are the participants age, when compared to both Hetu et al. (1998) and Thompson et al. (2004) studies, and the use of plyometrics in the case of Fletcher and Hartwell (2004) and Doan et al. (2006) studies.

Turning to the sport of tennis, Kraemer et al. (2000) investigated the effects of a nonlinear periodised strength training programme in comparison to a low volume heavy-resistance circuit programme over nine months in competitive female players. The study utilised 24 collegiate level female tennis players all of whom had similar tennis experience (7.8±2.4 yr) and were assigned to either a control group (n=8), single-set circuit group (n=8) or periodised training group (n=8). Both intervention groups trained 2-3 days per week, depending on match schedule, using the exact same exercises that included leg press, bent over rows and bench press. Throughout the intervention the single set group used a weight that allowed them to perform 8-10 repetitions for each exercise, whereas the periodised group used either 4-6 repetitions (heavy resistance), 8-10 repetitions (moderate resistance) or 12-15 repetitions (light resistance) for 2-4 sets. Outside of the training intervention all three groups participated in regular tennis-specific training and conditioning drills. At the conclusion of the intervention the authors found that the periodised group experienced significant increases in bench press, shoulder press and leg press 1RM across all three time points (months 4, 6 and 9). However, the circuit group only experienced significant changes between baseline and month 4 with no changes recorded for the control group. The periodised group also experienced a concomitant increase in serve velocity (month 9 Δ =29% p=≤0.05) whilst neither the circuit or control group experienced a significant change.

Building on this research Kraemer et al. (2003) wanted to compare the effects of both a nonlinear periodised programme and a non-periodised training programme in competitive female tennis players to see which would provide the largest improvement in performance. Again three groups were utilised with 27 participants (tennis experience = 8.1±3.5 yr) split among the nonlinear group (n=9), non-periodised group (n=10) and control group (n=8). Training took place 3 days per week with the non-periodised group performing three sets using a weight that allowed for 8-10 repetitions in each exercise and the nonlinear group using either 4-6 repetitions, 8-10 repetitions or 12-15 repetitions for three sets. Similar to the previous study both intervention groups performed the same exercises with a full body workout being used each session, the only difference was that session two used different exercises from session one and three. Both groups made significant increases in leg press, bench press and shoulder press 1RM however, the nonlinear group had significantly greater increases at the end of the intervention. Of particular interest in this study is that the authors measured not just serve velocity but also forehand and backhand velocity. Ball velocities increased significantly for both groups but percent increase was greater in the serve (29%vs.16%), forehand stroke (22%vs.17%), and backhand stroke (36%vs.14%) for the nonlinear group. Though these are the results of only two studies and the populations are similar, both female and experienced, it would seem that strength training is able to increase a player's ball velocity for a range of strokes. Together with the results of the golf studies it would seem that strength training does have the ability to increase sport specific performance in ball striking sports. However, the results of the two sports do differ in that the tennis studies did not require any rotational plyometrics whereas golf did for more qualified players. Therefore until more research is performed it would likely be pertinent to include some sort of rotational plyometric exercise in the strength training programme of ball striking sports.

Conclusion

Though there is a limited number of studies it would seem that there is a significant relationship between lower body strength and sprint performance in youth athletes when the back squat, a global isoinertial assessment, is used. However, there is a paucity of studies using either other exercises or assessment methods. Exercises, such as the deadlift and IMTP, have been shown to have strong relationships with sprint performance in adults therefore future studies might investigate whether the same is true in youth athletes. Though there is a limited number of studies exploring the relationship between lower body strength and sprint performance, the literature seems united on the fact that lower body strength training significantly improves sprint performance in youth athletes. Given the role of the hip extensors in sprinting it would be worthwhile for future research to examine whether exercises targeting the hip musculature are more effective as to date only two studies have examined this with each reporting conflicting results. While lower body strength and strength training have been investigated so far no studies have examined the role of shoulder girdle strength in either youth or adult athletes. From the research available it would seem that the thoracolumbar fascia allows for force transmission between both the shoulder girdle and hip extensor complex. Considering this transmission and the potentially small but important role that the shoulder girdle muscles play in sprinting, future research might look to establish firstly whether the relationship is significant and positive and secondly the effect that strengthening these muscles has.

Despite the range of sports that utilise ball striking with an implement there is a lack of literature looking at the relationship between ball speed or IHS and either lower or upper body strength. The majority of work to date, which has been performed in adults, suggests that there is a significant relationship with both lower and upper body strength. In particular shoulder girdle strength seems to have a significant relationship with both ball speed and IHS in adults, though so far this has not been established in youth athletes. From the two studies performed in adults there seems to be a significant relationship between isometric strength and ball striking performance. More research is needed however to verify this relationship and to establish whether a similar relationship exists in youth athletes. In training studies the literature shows that strengthening the shoulder girdle and hip extensors increases performance. Though due to discrepancies in methods and results more research is needed to determine whether a rotational plyometric exercise is needed to see improvements. As current literature suggests that youth athletes do no respond the same to training interventions as adults, researchers need to establish whether strengthening the shoulder girdle and hip extensors will improve ball striking performance.

Chapter 3

Reliability of an Isometric Hip Thrust and Lateral Pulldown Assessment

Preface

Given the muscle recruitment strategies for sprinting and ball striking reported in Chapter 2, as well as the relationships described between them and different isoinertial strength assessments, this chapter will focus on the inter-session reliability of two new isometric strength tests. Prior research has highlighted that in youth team sports whilst sprinting athletes develop force in ≤200ms, similar results have also been reported during a golf swing. Therefore this study will look to establish both the methods and reliability for an isometric lateral pulldown and hip thrust, with early impulse being measured over the first 250ms.

Abstract

The aim of this study was to establish the test-retest reliability of a portable custom-built isometric hip thrust (IHT) and isometric lateral pulldown (ILP) assessment that utilised a single axis load cell. Ten male participants with ≥2 years of structured resistance training experience participated. For the IHT participants wore a dip belt, positioned themselves across two boxes, as if to perform a hip thrust, and asked to lower their hips until they reached 40°± 10° of hip flexion. They were then secured via safety clip to the strain gauge which was in turn secured to the base of a power cage. For the ILP a lateral pulldown bar was attached to a strain gauge (height adjusted so there was 60°±5° of shoulder abduction) which in turn was secured to a barbell in a power cage via chains and safety clips. Whilst seated participants leant back until they reached 70°± 5° of hip flexion and were then fixated with straps to the power cage. The IHT had a relatively small (6%) mean difference (MDiff) and effect size ([ES] 0.14) indicating moderate to good reliability between testing sessions. A test-retest intraclass correlation (ICC) of 0.97 in combination with a coefficient of variation (CV) of 7.3% indicates a small average variability. A small MDiff (4%) and ES (0.17) are indicators of good reliability for ILP's inter-session performance. While an ICC of 0.9 and a CV of 8.1% indicates that the average variability between sessions was small. The IHT and ILP assessments both demonstrated high inter-session reliability for impulse at 0-200ms.

Introduction

Isometric assessments can be used to monitor an athlete's ability to adapt to a training programme as well as determine potential relationships with measures of performance during dynamic movements such as sprinting (West et al., 2011). Isometric tests have been shown to be highly reliable (James, Roberts, Haff, Kelly, & Beckman, 2016) as well as potentially more time efficient and relatively less fatiguing than traditional 1RM testing. Isometric testing also allows for the measurement of impulse ($F\Delta t$). In certain sporting movements such as golf where force development occurs at high speeds (≤200ms)(Hume et al., 2005) and against a constant load impulse might be of more interest than peak force.

The barbell hip thrust has become a popular way to train the gluteus maximus and other hip extensor muscles. A recent study found that the barbell hip thrust elicited greater EMG activation of the gluteus maximus than either the conventional deadlift or hexagonal bar deadlift (Andersen et al., 2018). When compared to the back squat the hip thrust was found to have both higher gluteus maximus and bicep femoris activation (Contreras et al., 2016). The lateral pulldown is a common exercise used to strengthen the latissimus dorsi and other shoulder girdle muscles. Across various EMG studies it has been found that for maximal latissimus dorsi activation grip width is not important (Lusk, Hale, & Russell, 2010). However, anterior lateral pulldowns were shown to have greater activation than posterior lateral pulldowns (Signorile, Zink, & Szwed, 2002).

The present study had two key objectives. The first objective was to establish the test-retest reliability of a portable custom-built isometric hip thrust (IHT) that utilised a single axis load cell. The second was to establish the test-retest reliability of a custom built portable isometric lateral pulldown (ILP) that utilised a single axis load cell. It was hypothesized that both isometric assessments would reach acceptable levels of reliability therefore providing two new isometric tests.

Methods

Participants

Ten male participants (age: 26 ± 5.8 y; height: 1.77 ± 6.05 m; body mass: 78.46 ± 12.32 kg) with ≥2 years of structured resistance training experience participated in this study. As part of the inclusion criteria all participants were required to: (1) have prior experience performing a hip thrust and lateral pulldown, (2) be injury free at the time of testing and (3) not be currently taking any medications/drugs. All participants were made aware of the risks associated with participation in this investigation and provided written informed consent. This experiment was made in accordance with and approved by Auckland University of Technology Ethics Committee (AUTEC) (No. 16/358).

Design

A repeated measures study design was used to assess the inter-session reliability of impulse for the IHT and ILP. Participants were tested on 3 separate occasions (with the first session acting as a familiarization session) at the same time of day and separated by at least 48hrs. The best trial for each day, as determined by the highest impulse output, was used for analysis.

Procedures

Warm-Up

At the beginning of each session participants were given a standardised warm-up consisting of dynamic stretching and body-weight exercises. Each session began with the participant performing two progressively increasing submaximal attempts, described as a perceived 50% and 75%, lasting 3s with 60s rest between each attempt.

IHT Protocol

For the IHT each participant wore a dip belt (Schiek Sports, Inc. Oshkosh, Wisconsin) which was placed close to the top of the iliac crest. This was tightened as much as possible to try limit fabric deformation. Participants were asked to position themselves across two boxes (height= 44.5cm and 20cm) as if they were going to perform a hip thrust. Eleiko weightlifting plates (Eleiko, Halmstad, Sweden) were then used to increase the height of the participant if needed so that they were approximately parallel to the floor when in full hip extension. Once in the top position they were asked to slowly lower their hips until they reached 40°± 10° of hip flexion. They were then secured via safety clip to the strain gauge (MT501 Universal Load Cell, with a 500kg maximum, Millennium Mechatronics, Auckland, New Zealand) which was in turn secured to the base of a power cage (FT700 Power Cage, Fitness Technology, Australia)(See figure 3).

ILP Protocol

For the ILP the strain gauge was attached to a barbell in the power cage using chains and safety clips. A standard lateral pulldown handle was attached to the other end of the strain gauge. Each participant wore a harness (Pure Power Multi Harness, R80, Speed Power & Stability Systems (SPSS) New Zealand Ltd) and was seated on a standardised box (height= 44.5cm). Participant's hands were placed on the bar so their wrists were in alignment with their elbows. Chain length was adjusted so that there was 60°±5° of shoulder abduction (measured using a goniometer) and slight horizontal shoulder flexion (Park & Yoo, 2013). To limit the potential use of the pectoralis major each participant was asked to lean back until they reached 70°± 5° of hip flexion and then fixated with straps (See figure 3).

Figure 3. Setup for isometric testing.

Isometric Lateral Pulldown (top two images) and Isometric Hip Thrust (bottom two images)

Assessment of Isometric Force

For maximal attempts participants were given a 3s countdown and then instructed to pull on the bar or extend their hips "as hard and as fast as possible" for the 3s. Force output was monitored in real time by the tester with strong verbal encouragement given for each maximal attempt. The three trials in each session were separated by 2 minutes of passive recovery. If the tester perceived that an attempt was less than maximal or there was a greater than 250 N difference between the current and preceding trial the trial was discarded and repeated.

Assessment of Force-Time Curve

The strain gauge (sampling at 1000 Hz) was interfaced with customised software (Labview) that allowed for the direct measurement of force-time characteristics and their analysis. During the 3s countdown participants were required to stay still so a clear baseline could be established. Data was filtered using a 10 Hz low pass Butterworth fourth-order digital filter. Muscle contraction onset was defined as the time point at which the force curve deflected away from baseline by 2.5% of the difference between the baseline and MVC (Andersen, Andersen, Zebis, & Aagaard, 2010).

Data analysis

Data are presented as means and standard deviations (SD) to represent centrality and spread (Table 1). Between session change is expressed as percent difference and ES (pre-test minus post-test divided by the standard deviation of the pre-test). Standardised differences in the means were interpreted using the thresholds values of 0.20 (small), 0.60 (moderate), 1.2 (large), 2.0 (very large) and 4.0 (nearly perfect) (Hopkins, Marshall, Batterham, & Hanin, 2009). To provide an overall interpretation of the reliability of the two isometric assessments average reliability was interpreted as good (mean difference (MDiff) was ≤5% and the ES trivial to small), moderate (MDiff >5% or an ES of moderate to large) and poor (MDiff > 5% and an ES of moderate to large). Measures of variability used were intra-class correlation coefficients (ICC) and typical error of measurement expressed as a coefficient of variation percentage. Smallest worthwhile change (SWC) was calculated as the SD across both days multiplied 0.2 (small effect) or 0.6 (moderate effect) and then expressed as a percentage of the mean for the two days. SWC was divided by CV to produce a performance/noise ratio.

Table 1. Data for IHT and ILP across both sessions

Male (*N* = 10)	**Day 1**	**Day 2**						
Impulse (N·s)	*M±SD*	*M±SD*	Mdiff (%)	ES	ICC	CV (%)	SWC (%)	P/N
IHT	130±59	138±54	6%	*Small* (0.14)	0.97	7.3	8.5	1.2

ILP	103±30	108±27	4%	*Small* (0.17)	0.90	8.1	5.4	0.7

Values are means, SD, mean difference (Mdiff), effect size (ES), intraclass correlation (ICC), coefficient of variation (CV), smallest worthwhile change (SWC) and performance/noise ratio (P/N).

Results and Discussion

Reliability of IHT

As the MDiff was just over 5% (6%) it still could be considered quite small which when combined with a small ES (0.14) indicates moderate to good reliability for performance between testing sessions. The test-retest ICC was 0.97 indicating little variation for trials between the two sessions. A CV of 7.3% can be considered acceptable which in combination with an ICC of 0.97 indicates an small average variability (ICC > 0.67 and CV ≤ 10%)(Bradshaw, Hume, Calton, & Aisbett, 2010). SWC provides a statistical estimate of the minimum percentage change needed for a training effect to be considered significant which, for the IHT, was 7.3%. When the SWC score is combined with the CV it can create a performance/noise ratio with a score of 1 indicating that the variability was less than the smallest worthwhile change. With a ratio of 1.2 this suggests that any real performance change seen (more than the SWC) is likely due to an intervention rather than between session variability.

Overall these results suggest that the IHT is reliable and that a change in performance of ≥8.5% can be considered worthwhile.

Reliability of ILP

Together a small MDiff (4%) and ES (0.17) are indicators of good reliability for inter-session performance. An ICC of 0.9 indicates little variation between sessions which with an acceptable CV of 8.1% means that the average variability (ICC > 0.67 and CV ≤ 10%) between sessions was small. A performance noise ratio of 0.7, caused by a larger CV than SWC, suggests that when being used as an assessment practitioners should calculate the SWC using 0.6 rather than 0.2. This would make the SWC 16.3% and allow for any change to be considered worthwhile. Together the results indicate that the ILP is reliable and if the higher SWC of 13.5% is used the ILP can detect moderate changes in performance.

A limitation of this study is the use of chains which only allow for predetermined increases in length, therefore joint angles were only able to be approximated e.g. 40°± 10° of hip flexion in the IHT.

Conclusion

The IHT and ILP assessments both demonstrated high inter-session reliability for impulse at 0-200ms. Future research should look at both the use of heavy-duty ratchet straps for attachment to load cell, allowing for joint angles to be easily adjusted, and the reliability of the IHT at different hip angles.

Chapter 4

Relationship between Hip Extensor and Shoulder Girdle Strength, and Sprint Times and Ball Hitting Speed in Youth Field Hockey Athletes

Preface

Chapter 2 highlighted a gap in the literature surrounding the relationship between strength and performance markers in field hockey. The first step in establishing whether a relationship existed between the strength of the shoulder girdle and hip extensors and either/or sprint performance and ball speed was to establish the methods and reliability for two new assessments which was done in Chapter 3. The focus of the current chapter therefore was to establish whether a significant relationship exists between both hip and shoulder girdle strength and two performance measures (sprint and ball speed) in youth field hockey players.

Abstract

The aim of this study was to investigate and determine the relationship between both hip and shoulder girdle strength and two performance measures (sprint and ball speed) in youth field hockey players. Twenty-three youth male secondary school representative field hockey players (age = 16 ± 0.6 years, height = 1.76 ± 0.11 m, mass = 66.9 ± 9.4 kg) all with at least 1 year of strength training participated. Impulse, measured via isometric hip thrust and lateral pulldown, 40-m sprint performance with 10-m splits, and ball hitting speed were measured on two separate testing occasions. No significant relationships were found between sprint times and either of the isometric strength measures. Significant (p=0.000) large and positive correlations (r=0.68) were found between forehand ball release speed and isometric hip thrust results. Significant (p=0.046) moderate and positive correlations (r=0.42) were found between forehand ball release speed and isometric lateral pulldown results. Significant (p=0.025) moderate and positive correlations (r=0.47) were found between reverse ball release speed and isometric hip thrust results. Exercises that utilise similar movement patterns or musculature as these two assessments may potentially lead to improvements in ball speed, though a training study would be needed to corroborate this.

Introduction

Elite male field hockey players can spend up to five percent of match time in high-intensity striding and sprinting (Spencer et al., 2004). Despite studies having investigated the relationship between strength and sprint performance in other team sports so far none have utilised hockey players. Two methods used in the literature when examining the relationship between strength and sprint performance are isoinertial assessments (often employing free weight exercises) and isometric assessments. Results of studies differ, perhaps in part due to the range of strength assessments used, as well as how the strength values are expressed. For instance, strong relationships were found when allometric scaling was used with the deadlift (Swinton et al., 2014) while in the back squat absolute strength was found to have the best relationship (Wisloff et al., 2004). The most commonly used isometric assessment is the mid-thigh pull which had the strongest relationship to sprint performance when impulse, rather than peak force, was used (Thomas et al., 2015). Intuitively, impulse is of more importance than peak force when trying to predict sprint performance as foot contact times of ≤200ms have been found in both adult (Lockie, Murphy, Callaghan, & Jeffriess, 2014) and youth team sport athletes (Rumpf et al., 2015).

The role of the upper extremities in sprinting has not been investigated thoroughly. For running it has traditionally been thought that the arms provide balance and stability to the runner in motion, counterbalance the rotational forces of the torso during the stance phase, stabilise the torso and assist in the generation of forward momentum during the running cycle (Nicola & Jewison, 2012). It has been suggested that during running the arms may contribute a small (5-10%) but important part to the total vertical impulse generated by the body during the contact phase (Hinrichs et al., 1987). This upward acceleration or lift is advantageous as it allows the leg drive to be directed more horizontally and was found to increase as running speed increased. To date only one study has looked at the relationship between an upper-body strength measure and sprint speed, reporting a significant correlation between bench press power and 36.6-m sprint performance (Luhtanen & Komi, 1978).

The effectiveness of shots in field hockey can essentially be evaluated using three different variables: ball speed, accuracy in reaching the intended target and the time it takes to execute the shot (a shorter time limits the chance of the shot being intercepted) (Brétigny, Leroy, Button, Chollet, & Seifert, 2011). One of the most common shots is the drive or forehand which is distinguished by the hands being joined at the top of the stick as opposed to the short grip drive where the hands are joined but lower down on the stick (Bretigny et al., 2008). The forehand shot is the most powerful and is predominantly used for shooting at the goal and long range passing.

While no studies have examined the relationship between strength and ball velocity in field hockey some potential insight can be derived from other striking sports such as baseball and golf. Various relationships between both upper and lower body strength and club head speed (CHS) have been reported. For example, in 10 low handicap and 10 high handicap male golfers a significant correlation was found between predicted 1RM hack squat and CHS (Keogh et al., 2009).

The aim of this study was twofold. The first was to determine the relationship between hip strength and two hockey field performance measures (sprint speed and ball speed) in youth hockey players. The second was to determine the relationship between the same field performance tests and shoulder girdle strength. We hypothesized that the participants who produced the greatest ball speeds and fastest sprint times would also be the strongest in the shoulder girdle and hip complex strength tests.

Methods

Study design

To examine the relationship between the strength and field performance measures two testing sessions were conducted. The first was to determine hip extensor and shoulder girdle strength while the second was to assess sprint time, and ball speed. Participants were told to refrain from any additional resistance or plyometric training before testing. The week before the testing session participants were familiarised with the isometric assessments.

Participants

All participants who took part in this study were youth male field hockey players (n= 23, age = 16 ± 0.6 years, height = 1.76 ± 0.11 m, mass = 66.9 ± 9.4 kg) and represented their secondary school team. All participants were experienced in playing field hockey, had a strength training history of at least one year and reported no current injuries. Before taking part all participants were informed about the potential risks involved in the study and gave their written informed consent. This study was conducted in accordance with and approved by Auckland University of Technology Ethics Committee (AUTEC) (No. 16/358).

Measures

Isometric strength protocol

Two novel isometric strength assessments were employed to measure hip extensor and shoulder girdle strength. Shoulder girdle strength was assessed using an isometric lateral pulldown while hip strength was assessed using an isometric hip thrust. A preliminary reliability study (see Chapter 3) established the lateral pulldown assessment had an intra-class correlation coefficient (ICC) of 0.97 and coefficient of variation (CV) of 7.3% while the hip thrust assessment recorded an ICC of 0.90 and CV of 8.1%.

The testing protocol required each participant to perform two submaximal attempts of increasing intensity (perceived 60% and then 80% of maximum) before then performing three maximal attempts each lasting 3s. Participants were given 60s rest between each of the submaximal attempts and 2min between each of the maximal attempts. During each attempt participants were instructed to either push or pull (depending on the assessment) as "hard and fast" as possible for the 3s with verbal encouragement given throughout. For both assessments impulse was calculated using the first 250ms of force production and the best of the 3 attempts were recorded for analyses.

Sprint protocol

Prior to testing participants performed a standardised warm-up that included jogging, static and dynamic stretching and several acceleration runs. Wireless infra-red single beam timing lights (Smartspeed, Fusion Sport, Brisbane, Australia) were utilised to assess sprint performance.

The integrated system is connected to the timing lights via a wireless personal digital assistant (PDA; Hewlett Packard, Palo Alto, CA, United States) and has built-in error correction software. The timing lights have a sampling rate of 1.8MHz however, this was rounded to the nearest 0.01s. The timing system has a reported typical error of 0.03s over 10-m, 0.03s for 20-m and 0.04s for 30-m (Bradshaw et al., 2010).

To reflect standard hockey sprint test protocols (Reilly, 2001), we utilised 40-m sprints, with split times at 10, 20, and 30-m. Timing lights were set at a height of 1-m with players instructed to adopt a staggered stance with their lead foot placed on a line 0.5-m behind the first pair of timing lights. Testing was undertaken on a standard water based synthetic turf hockey pitch.

Ball release speed protocol

Ball release speed testing was undertaken on a standard synthetic hockey pitch. A regulation hockey ball was placed perpendicular to the goal on the shooting circle (14.63-m from goal). A radar gun (Stalker Pro 2, Applied Concepts,Inc./Stalker Radar, Texas, U.S.A.) was placed behind the goal and directed towards the ball. Participants were given 10min to warm up both forehand and reverse shots (as they would use them in game) after which they were each given four practice shots directly before each style was tested. In a game context these shots are made while a player is in motion. However, to limit any confounding factors regarding the effect of each participant's individual speed of approach, each participant was allowed to take only two steps before executing the shot. Participants were allowed four shots using each shooting style with the best attempt, the highest recorded speed to get in the goal, being recorded for each style and subsequently used for analysis.

Statistical Analysis

The descriptive data are presented as means and standard deviations (SD) to represent centrality and spread (table 2). Normality was tested using the Shapiro-Wilk statistic in SPSS (version 22, SPSS Inc, Chicago, IL). All performance measures were found not to be normal (≤0.05) while strength measures were found to be normal. All data was then log transformed, using natural log, and expressed as a percentage in excel (100*LN). A Pearson's correlation matrix was produced for all variables. Checks for multicollinearity (r=≥0.8) were used to identify whether any variables contributed to collinearity. After identifying and removing variable(s) contributing to collinearity the remaining variables were entered into a new matrix where they were correlated with the dependent variables. To determine whether a correlation was statistically significant ($p \leq 0.05$) the alpha level was set at 0.05. When interpreting the mechanistic importance of individual variable correlations the following scale was used ≤ 0.10 (trivial), 0.10 (small), 0.30 (moderate), 0.50 (large), 0.70 (very large), 0.90 (nearly perfect) and 1.0 (perfect) (Hopkins et al., 2009). Only variables that showed a significant moderate or higher correlation (r=≥0.3, p=≤0.05) were considered important enough to use in the multiple regression equation. Based on the correlation matrix a stepwise linear regression model was produced for both reverse ball speed (isometric hip thrust and forehand ball speed) and forehand ball speed (isometric lateral pulldown and reverse ball speed). Despite showing significant correlations independently both models produced excluded isometric lateral pulldown and reverse ball speed. Correlation and regression analyses were performed using SPSS (version 22, SPSS Inc, Chicago, IL).

Results

Relationship between strength and sprint times

No significant relationship was found between sprint performance across any distance and either of the isometric strength measures (table 3).

Table 2. Descriptive statistics for strength and performance measures

Performance Variable	Mean ± SD
Hip Thrust Impulse (N · s)	150±58.5
Lateral Pulldown Impulse (N · s)	95±45.2
10-m (s)	1.86±0.1
20-m (s)	3.21±0.18
30-m (s)	4.49±0.27
40-m (s)	5.78±0.36
Forehand Speed (m/s)	29.07±9.98
Reverse Speed (m/s)	20.74±12.09

Values are means ±SD, Newton's per second (N · s), seconds (s) and metres per second (m/s)

Relationship between strength and ball speed

Significant large and positive correlations (r=0.68, *p*=0.000) were found between forehand ball release speed and isometric hip thrust results. Significant moderate and positive correlations (r=0.42, *p*= 0.046) were found between forehand ball release speed and isometric lateral pulldown results. Significant moderate and positive correlations (r=0.47, *p*= 0.025) were found between reverse ball release speed and isometric hip thrust results. Non-significant small and positive correlations (r=0.27, *p*= 0.219) were found between forehand ball release speed and isometric lateral pulldown results.

Table 3. Correlations of all predictor variables to measures of performance

	Hip Thrust	**Lateral Pulldown**
10-m	0.06 (*p*= 0.781)	-0.16 (*p*= 0.472)
20-m	0.15 (*p*= 0.493)	-0.07 (*p*= 0.738)
30-m	0.14 (*p*= 0.534)	-0.06 (*p*= 0.770)
40-m	0.15 (*p*= 0.488)	-0.06 (*p*= 0.802)
Forehand Speed	0.68** (*p*= 0.000)	0.42* (*p*= 0.046)
Reverse Speed	0.47* (*p*= 0.025)	0.27 (*p*= 0.219)

Correlations are presented as R-values. * p= ≤ 0.05, ** p= ≤ 0.01.

Discussion

The purpose of this study was to investigate and determine the relationship between hip strength and/or shoulder girdle strength, sprint performance and ball release speed in youth field hockey players. The results showed there was significant moderate to large correlations between performance in the isometric hip thrust and both forehand (r= 0. 0.68, *p*= 0.000) and reverse (r= 0.47, *p*= 0.025) ball speeds. Although not as strong, a relationship was also found between the isometric lateral pulldown and forehand ball speed (r= 0.42, *p*= 0.046) though not reverse ball speed (r=0.27, *p*= 0.219). Unexpectedly and in contrast to our hypothesis no significant correlation existed between either strength measure and sprint performance across any of the distances tested.

Insignificant (*p*= >0.05), trivial to small (r= 0.061 – 0.152) positive correlations were found between the isometric hip thrust and sprint times. Due to the isometric hip thrust having not been used in the literature before it is hard to determine whether these results are to be expected. Previous studies that used isometrics predominantly used the isometric mid-thigh pull (IMTP) which in adults has shown varying relationships to sprint performance. Conlon, Haff, Nimphius, Tran, & Newton (2013) reported that, in 139 athletes from a range of sports (individual and team sports), large correlations (r= -0.578 to -0.612) were reported between IMTP peak force and sprint performance for 5-m to 30-m. In contrast, there was no significant correlation between peak force and 10-m (r=-0.289) or 20-m (r=-0.249) performance in 25 English premier league soccer players (Jonathan et al., 2017b).

With mean contact times of less than 200ms having been recorded for both adult and youth team sport athletes during the acceleration phase of sprinting it might be advisable to measure peak force or impulse over specific time bands rather than for the entire time of the test (Lockie et al., 2014; Rumpf et al., 2015). A study by Thomas et al. (2015) of 14 male collegiate level rugby and soccer players found that impulse, in the IMTP at 100ms was significantly (p= ≤0.01) negatively correlated to both 5-m and 20-m times (r=-0.71 and -0.75 respectively). Interestingly these correlations were larger than those found in the same study between peak force and sprint times (p= ≤0.05 r=-0.57 and p= ≤0.01 r=-0.69) though not for impulse at 300ms (p= ≤0.01 r=-0.74 and p= ≤0.01 r=-0.78). Therefore with very large correlations being reported for both 100ms and 300ms a sampling time of 250ms as used in this study should not be the reason for a lack of correlation. A potential reason for a lack of significant correlation between the isometric hip thrust and sprinting might be due to technicalities in the assessment procedure. Previous research (Murphy, Wilson, Pryor, & Newton, 1995) has established that the angle at which isometric testing is performed, in this case the hip angle, has a profound impact on the relationship between the isometric assessment and the dynamic assessment. The participant's age, lower training history and playing level might also account for the discrepancy between the results of this study and others. These factors in combination with a lack of formal coaching on sprint mechanics could indicate a potential lack of stabilisation in sprint technique. If true this would impact the ability of the participants to efficiently utilise their strength potential while sprinting.

Similar to the hip thrust no significant correlations were found between the isometric lateral pulldown and sprint times over any distance. While still insignificant (p= >0.05) and trivial (r= -0.055 to -0.158) unlike the isometric hip thrust more traditional negative correlations were found between the isometric lateral pulldown and sprint performance. The lack of correlation between the isometric lateral pulldown and sprint performance is surprising. Prior findings (Mooney, Pozos, Vleeming, Gulick, & Swenski, 2001; Shin, Kim, & Yoo, 2013) suggest that latissimus dorsi EMG increases concurrently with gait velocity. Though no research has looked at sprinting it would seem likely that the results would be similar in which case although small there should be some significant correlation between latissimus dorsi strength and sprint performance. Efficient arm swing is a characteristic of elite sprinters with coaches reporting that having the arms move exclusively in the sagittal plane is of particular importance (Thompson, Bezodis, & Jones, 2009). Hockey players are used to sprinting carrying an implement which does not allow for the utilisation of the shoulder girdle and therefore arm in the usual fashion. The arm swing used in traditional sprinting has been found to contribute a small but significant amount of lift (Hinrichs et al., 1987). Therefore as previously mentioned a lack of significant correlation might be due to the athletes having no formal coaching and therefore use of poor technique such as arms crossing over the centre line.

Significant moderate to large positive correlations were found between the isometric hip thrust and both forehand (*p*= 0.000, r= 0. 0.68) and reverse (*p*= 0.025, r= 0.47) ball speeds suggesting that those who produced the most impulse in the hip thrust had the highest ball release speed for both shots. Due to the lack of literature surrounding field hockey it is difficult to tell whether the results found are common or not therefore they will be compared with those of other hitting sports. The forehand shot shares similarities, with regards to movement pattern, to select movements in golf and baseball. However, due to fundamental differences in the sports the literature will be broadly interpreted. An EMG study of 18 professional baseball batters (age= 19-44 years) found that the gluteus maximus was most active in the pre-swing phase and the early stages of the swing phase (Shaffer et al., 1993). Both of these phases have been found to be when batters generate the most force (Welch et al., 1995). Similar activation patterns, though to a slightly higher level in the pre-swing phase, were also found for the biceps femoris and semimembranosus (Shaffer et al., 1993) with similar patterns for the gluteus maximus and biceps femoris being reported in non-professional players (Reyes et al., 2011). Similar activation patterns have also been reported for the golf swing with the gluteus maximus having its highest level of activation during the down/forward swing phase (Bechler et al., 1995). This phase of the golf swing is comparable to the pre-swing phase in baseball as it is the period when the largest forces are produced and the intention is to move the implement as fast as possible (Hume et al., 2005). In golf the majority of correlational studies have found a moderate to large (r=0.49 – 0.597) relationship between CHS and lower body strength. In a study of 33 elite male Swedish golfers (age = 18-30 years) Hellström (2008) found a significantly large (*p*= ≤ 0.01 r= 0.54) relationship between CHS and back squat 1RM. While a study of 101 male recreational golfers (age 17- 71 years) found an even larger correlation (*p*= ≤ 0.05 r= 0.56) between CHS and isometric mid-thigh pull (Loock et al., 2013). Though only partial similarities exist between the aforementioned movements and the forehand shot in hockey the literature would seem to suggest that a significant correlation, even if only small, should exist between ball speed and the isometric hip thrust.

While significant moderate positive correlations were found between the isometric lateral pulldown and forehand ball speed (*p*= 0.046, r= 0.42) no statistically significant correlations were found between the isometric lateral pulldown and reverse ball speed (*p*= 0.219, r=0.27). These findings would seem to imply that there is some relationship between the amount of impulse produced through a lateral pulldown and a player's ability produce high forehand ball speeds. An EMG study by Kumar & Narayan (2006) that measured the activity of various muscles used in performing rotation extension of the torso from a pre-rotated and flexed position found that the ipsilateral latissimus dorsi was a key muscle in producing force. As this was an isometric study the pre-rotated and flexed position is important as from observation this would be similar to the position that a hockey player would find themselves in before initiating a ball striking sequence. An EMG study of 13 professional golfers found similar results with latissimus dorsi activation peaking during the forward swing and acceleration phases at which point the player is trying to accelerate the club as fast as possible (Jobe et al., 1989). This idea is further supported by the results of a study by Wells et al. (2009) who found when testing the Canadian National Golf Team that the pull-up had a very large correlation (r= 0.8, p= ≤0.0001) with CHS. With regards to the reverse shot the only other similar movement that has been researched is the tennis backhand which was found to have moderate activation during the acceleration phase (Ryu et al., 1988). In the same study the infraspinatus was found to have the second highest activation level of all the muscles measured including the latissimus dorsi. This is of importance as a study by Andersen, Fimland, Wiik, Skoglund, and Saeterbakken (2014) found that the infraspinatus had a high level of activation in the lateral pulldown.

More research is needed on field hockey with regards to quantifying kinematic models of sprinting and hitting and what exercises have strong correlations to these movements. Future research should first focus on developing a better understanding of the key muscles utilised in field hockey sprinting and shooting through the use of EMG. Once the muscular demands are better understood then other correlational studies can be carried out to determine the extent that the strength of these muscles are important. Training studies can also be implemented to see whether increasing muscular strength in specific areas has a significant impact on sprint times and ball speeds in hockey players.

Conclusion

This is the first study to examine the relationship between the isometric hip thrust and lateral pulldown and either sprint ability or ball speed in field hockey or any other sport. In this cohort of youth field hockey player's significant correlations were found to exist between the isometric hip thrust and both the forehand and reverse shot. Similarly correlations were found between the isometric lateral pulldown and forehand shot but not the reverse shot. Unexpectedly no significant correlations were found between either strength measure and sprint performance over any distance. Due to the correlations between the isometric assessments and ball speeds these assessments could potentially be a valid way of tracking meaningful strength improvements across a training period. Additionally exercises that are found to utilise similar movement patterns or musculature as these two assessments may potentially lead to improvements in ball speed, though a training study would be needed to corroborate this.

Chapter 5

Effect of 5 Weeks of Hip and Shoulder Girdle Dominant Training on Sprint Performance and Ball Release Velocity

Preface

Though significant correlations have been established between the isometric tests and some of the performance measures in Chapter 4 this does not imply causation. Therefore the focus of this chapter, and the final study, will be to determine if strengthening the hip complex and shoulder girdle will improve sprint performance and ball release speed in youth field hockey players.

Abstract

The aim of this study was to determine if strengthening the hip complex and shoulder girdle would improve sprint performance and ball release speed in youth field hockey players. Ten youth male secondary school representative field hockey players (17 ± 0.2 years, height = 174.1 ± 10.8 cm, mass = 66.78± 8.4 kg) all with at least 1 year of strength training took part in a 5 week training protocol focusing on hip and shoulder girdle strength. Strength, measured via isometric hip thrust and lateral pulldown, 40-m sprint performance with 10-m splits and ball speed were measured before and after 5 week training period. Strength training resulted in significant large and positive improvements in both isometric hip thrust (p=≤0.000, ES = 1.21, +52.6%) and isometric lateral pulldown (p=0.007, ES = 1.46, +63.4%) and non-significant trivial and small positive improvements in forehand and reverse ball speed respectively (p=0.813, ES = 0.09, +1.15%, p=0.303, ES = 0.27, 4.95%). However, significant small and negative decrements were experienced in 10-m (p=0.03, ES = 0.57, 2.67%), 30-m (p=0.016, ES = 0.44, 2.21%) and 40-m (p=0.016, ES = 0.43, 2.24%) sprint performance while non-significant (p=≤0.07) small and negative decrements (ES = 0.31, 1.55%) were found for 20-m. Despite the performance parameter results being less than ideal, when the individual results are combined with those of previous studies it would seem as if there is merit in using more hip and shoulder girdle dominant exercises when trying to improve both sprint and ball speed performance.

Introduction

In elite male field hockey 5% of match time is spent in high-intensity striding and sprinting (Spencer et al., 2004). Despite this, to date, no studies have examined the effect of strength training on sprint performance in this cohort. A meta-analysis (Seitz et al., 2014) reported that there was a positive association between increases in lower body strength and improvements in sprint performance. In all the studies reviewed only the back squat (to parallel) was used as a measure of lower body strength. Only two studies in the current literature have included exercises other than the squat when examining the effect of lower body strength training on sprint performance. Speirs, Bennett, Finn, and Turner (2016) compared the effect of unilateral versus bilateral lower body strength training on sprint performance. A moderate positive effect (ES=0.47) was found between both unilateral and bilateral strength measures and 40-m performance, but no significant effect was found between either strength measure on 10-m performance (ES=0.14). An investigation into the effect of either six weeks of hip thrust training or front squat training on sprint speed in a group of adolescent athletes (n=28; age= 15-17 years) found that the hip thrust group experienced a 1.7% decrease in 20-m sprint time, whereas the front squat group experienced a 0.67% decrease (Contreras et al.).

An often overlooked aspect of sprinting is the role of the upper extremities in the sprint action. Traditionally in running the involvement of the arms is thought to provide balance and stability to the runner in motion, counterbalance vertical angular momentum during propulsion of the stance phase, stabilise the torso and assist in the generation of forward momentum during the running cycle (Nicola & Jewison, 2012). It has been reported that in running the arms provide a small (5-10%) but still important part of the total vertical impulse generated by the body during the contact phase (Hinrichs et al., 1987). This upward acceleration or lift is advantageous as it allows the leg drive to be directed more horizontally and was found to increase as running speed increased. To date no studies have examined the effect of upper-body strength training on sprint performance. It has been suggested that during short sprints, where there is a pronounced forward lean, the upward lift generated by the arms would have a forward component directly contributing to horizontal propulsion (2001). Therefore an increase in shoulder girdle strength should also have a concomitant increase on sprint performance during the acceleration and maximal speed phases.

In field hockey the effectiveness of any shot can essentially be evaluated according to three different parameters: ball velocity, accuracy in reaching the goal or intended teammate, and the time taken to execute the shot (a shorter time limits the opportunities for an opponent to intercept)

(Brétigny et al., 2011). Two of the most common shots are the drive or forehand which is distinguished by the hands being joined at the top of the stick and the short grip drive where the hands are joined but lower down on the stick (Bretigny et al., 2008). The forehand shot is the most powerful and is predominantly used for shooting at the goal and long range passing.

No studies have examined the effect of strength training on change in ball velocity in hockey players over an intervention period. Some potential insight can be derived from golf which has a similar form of striking and where the effect of different types of training interventions on club head speed (CHS) have been reported. At the end of an 8 week training study it was found that the intervention group (n=6; age= 29 ± 7.4 years), who used free weight exercises and medicine ball rotational exercises, experienced a 1.5% increase in CHS in comparison to a 0.5% increase by the control group (Fletcher & Hartwell, 2004). In comparison a study using a group of adolescent (n=10; age= 15.8 ± 2 years) golfers found that after 9 weeks of a full body resistance training programme twice a week CHS increased by 1.2% (Seiler, Skaanes, & Kirkesola, 2006). The only study to report ball speed found that after 8 weeks of resistance training using elastic tubing ball speed was increased by 5% in a group of older golfers (n=15; age= 47.2 ± 11.4 years) (Lephart, Smoliga, Myers, Sell, & Tsai, 2007).

The present study had two main objectives. The first was to determine if strengthening the hip complex and shoulder girdle would improve sprint performance in youth field hockey players. The second aim was to investigate the effects of the same intervention on ball release speed for two field hockey shots (the forehand and reverse shot). It was postulated that by implementing a targeted strength training programme the players would experience an increase in hip and shoulder girdle strength. We hypothesized that these gains in hip and shoulder girdle strength will facilitate a decrease in sprint time and an increase in forehand and reverse ball speed.

Methods

Experimental Approach to the Problem

The study utilised a pre-post single group study design over a five week period. Participants completed two fully supervised strength training sessions a week (Tuesday and Friday) and were required to maintain their usual field hockey practice. They were also told to refrain from any additional resistance or plyometric training. Two weeks before the initiation of the study participants were familiarised with the strength testing assessments and then a week later they took part in baseline testing. The same testing protocol was then repeated at the conclusion of the five week training intervention. Time of day (morning or afternoon) was maintained for testing procedures apart from sprint testing.

Subjects

All participants who took part in this study were youth male field hockey players (n= 10, age = 17 ± 0.2 years, height = 1.74 ± 0.11 m, mass = 66.79 ± 8.35 kg) and represented their secondary school team. All participants were experienced in playing field hockey, had a strength training history of at least one year and reported no current injuries. Before taking part all participants were informed about the potential risks involved in the study and gave their written informed consent. This study was conducted in accordance with and approved by Auckland University of Technology Ethics Committee (AUTEC) (No. 16/358).

Procedures

Training intervention

The resistance training protocol prescribed during the study is shown in Table 4. For each exercise participants were given a repetition range. To determine load athletes were told to try and complete as many repetitions as possible, within the repetition range, while maintaining good form. Once they were able to perform the maximum number of repetitions prescribed for the total number of sets they were advised to increase the load. Participants were advised to rest for 90-120 seconds between sets for all exercises except for the side medicine ball throw, which they were instructed to rest for 60 seconds between sets.

Table 4. Resistance training protocol

Exercise	Sets	Reps
Barbell Hip Thrust	4	8-12
Pull Up	4	8-12
Dumbbell Step Up	4	8-12
Barbell Bench Press	4	8-12
Single Arm Dumbbell Row	4	8-12
Side Medicine Ball Throw (2-4kg)	2	10-15

Isometric Strength Testing

Two novel isometric strength assessments were employed to measure hip and shoulder girdle strength. Shoulder girdle strength was assessed using an isometric lateral pulldown while hip strength was assessed using an isometric hip thrust. A preliminary reliability study (see Chapter 3) established the lateral pulldown assessment had an ICC of 0.97 and the hip thrust assessment recorded an ICC of 0.90.

The testing protocol required each participant to perform one submaximal attempt of increasing intensity before then performing three maximal attempts each lasting 3s. Participants were given 60s rest between each of the submaximal attempts and 2min between each of the maximal attempts. During each attempt participants were instructed to either push or pull (depending on the assessment) as "hard and fast" as possible for the 3s with verbal encouragement given throughout.

For both assessments impulse was calculated using the first 250ms of force production and the best of the 3 attempts were recorded for analysis. Participants had at least 3 days of recovery between their last training session and the first post intervention testing session.

Sprint Testing

Prior to testing participants performed a standardised warm-up that included jogging, static and dynamic stretching and several acceleration runs. Wireless infra-red single beam timing lights (Smartspeed, Fusion Sport, Brisbane, Australia) were utilised to assess sprint performance.

The integrated system is connected to the timing lights via a wireless personal digital assistant (PDA; Hewlett Packard, Palo Alto, CA, United States) and has built-in error correction software. The timing lights have a sampling rate of 1.8MHz however, this was rounded to the nearest 0.01s. The timing system has a reported typical error of 0.03s over 10-m, 0.03s for 20-m and 0.04s for 30-m (Bradshaw et al., 2010).

To reflect standard hockey sprint test protocols (Reilly, 2001), we utilised 40-m sprints, with split times at 10, 20, and 30-m. The timing lights were set at a height of 1-m with players instructed to adopt a staggered stance with their lead foot placed on a line 0.5-m behind the first pair of timing lights. Both pre and post testing was undertaken on a standard water based synthetic turf hockey pitch.

Ball Release Velocity Testing

Ball release velocity testing was undertaken on a standard water based synthetic turf hockey pitch. A regulation hockey ball was placed perpendicular to the goal on the shooting circle (14.63-m from goal). A radar gun (Stalker Pro 2, Applied Concepts,Inc./Stalker Radar, Texas, U.S.A.) was placed behind the goal and directed towards the ball. Participants were given 10min to warm up both forehand and reverse shots (as they would use them in game) after which they were each given four practice shots directly before each style was tested. In a game context these shots are made while a player is in motion. However, to limit any confounding factors regarding the effect of each participant's individual speed of approach, each participant was allowed to take only two steps before executing the shot. Each participant was allowed four shots for both shooting styles with the best attempt for both being recorded and used for analysis.

Statistical analysis

Normality was confirmed using the Shapiro-Wilk statistic in SPSS (version 22, SPSS Inc, Chicago, IL). The data are presented as means and standard deviations (SD) to represent centrality and spread (table 5). Changes in strength, sprint times and ball speed are expressed as percent change and effect sizes (pre-test minus post-test divided by the standard deviation of the pre-test). Standardised effects were interpreted using the thresholds values of ≤0.2 trivial, >0.2 small, >0.6 moderate, >1.2 large, >2.0 very large, and >4.0 extremely large (Hopkins, 2005). Qualitative descriptors of positive, neutral and negative are used to describe the change between post and pre values and its importance relative to the specific variable. Paired sample t-tests were used to determine if there were statistically significant differences ($p \leq 0.05$) between pre and post testing using an alpha level of 0.05. To better present the nuances of individual participant's responses to the training intervention data for isometric hip thrust, isometric lateral pulldown, 10-m sprint time, 40-m sprint time, forehand ball speed and reverse ball speed are presented as line charts (figure 4). As the trend for individual sprint performance did not change across the different distances only the 10-m and 40-m performances are depicted. The groups 90% confidence limits for the same performance measures are visually represented in figure 4.

Results

At the beginning of the intervention period 13 youth male field hockey players were recruited. However, 3 participants failed to complete the study, 1 due to undisclosed recurring injury and 2 due to individual circumstances. Of the 10 participants remaining there was a 95% compliance rate. Only 2 participants did not fully complete all the testing. The first was only able to complete one valid maximum test for the isometric lateral pulldown. The second was not able to make a reverse shot within the number of shots allowed and therefore was excluded from the analysis of the reverse ball speed release test. The results presented below therefore represent that of the 10 participants who finished the training intervention.

Table 5. Pre and post intervention descriptive data

Performance Variable	Pre	Post				
	Mean ± SD	Mean ± SD	% change	Effect Size (90% confidence intervals)	Inference	*p*
Hip Thrust impulse (N · s)	141.3 ± 56.2	215.7 ± 60.1	52.6	1.2 (0.85 - 1.57)	Large (positive)	0.000
Lateral Pulldown impulse (N · s)	85.4 ± 33.9	139.49 ± 64.3	63.4	1.46 (0.68 - 2.24)	Large (positive)	0.007
10-m (s)	1.87 ± 0.10	1.92 ± 0.08	2.7	0.57 (0.19 - 0.95)	Small (negative)	0.03
20-m (s)	3.23 ± 0.15	3.28 ± 0.12	1.6	0.3 (0.03 - 0.58)	Small (negative)	0.07
30-m (s)	4.52 ± 0.21	4.62 ± 0.44	2.2	0.4 (0.17 - 0.7)	Small (negative)	0.016
40-m (s)	5.81 ± 0.27	5.94 ± 0.22	2.2	0.4 (0.16 - 0.7)	Small (negative)	0.016
Forehand Speed (m/s)	31.2 ± 3.50	31.6 ± 2.39	1.2	0.09 (-0.6 - 0.79)	Trivial (positive)	0.81
Reverse Speed (m/s)	24.7 ± 9.69	25.9 ± 10	5	0.27 (-0.19 - 0.7)	Small (positive)	0.30

Values presented are means, % change and effect size for isometric strength, sprint speed and ball speed, Newton's per second (N · s), seconds (s) and metres per second (m/s)

Impulse

Significant (p=≤0.000) large and positive improvements (ES = 1.21 and CI = 0.85-1.57) in the isometric hip thrust (52.6%) were found overall for the group. Given the 90% confidence limits the true value of the effect however could lie somewhere between moderate and large. Significant (p=0.007) large and positive improvements (ES = 1.46 and CI = 0.68-2.24) in the isometric lateral pulldown (63.4%) were found overall for the group. Given the 90% confidence limits the true value of the effect however could lie somewhere between moderate and large.

Sprint performance

Significant (p=0.016) small and negative decrements (ES = 0.43 and CI = 0.16-0.70) in the 40-m (2.24%) were found overall for the group. Given the 90% confidence limits the true value of the effect however could lie somewhere between trivial and moderate.

Ball release speed

Non-significant (p=0.303) small and positive improvements (ES = 0.27 and CI = -0.19 – +0.72) in the forehand ball release speed (4.95%) were found overall for the group. Given the 90% confidence limits the true value of the effect however could lie somewhere between negatively trivial and positively moderate.

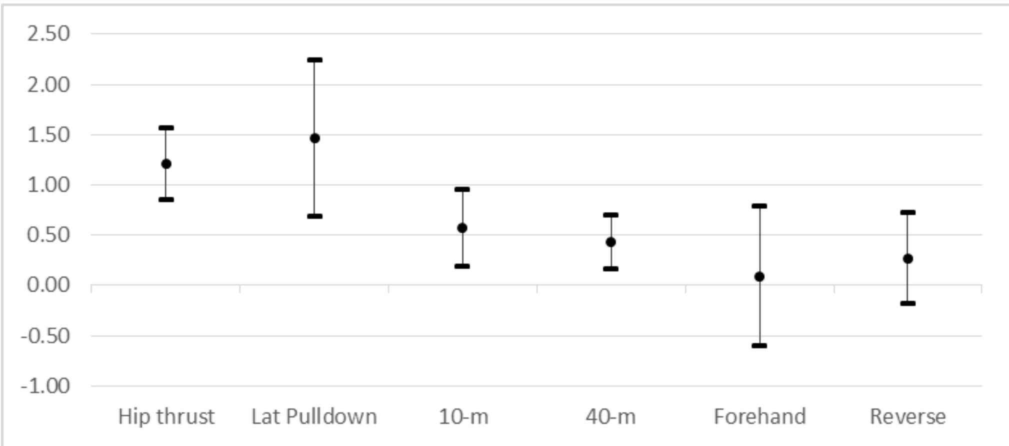

Figure 4. Group ES (90% confidence intervals) for selected performance variables

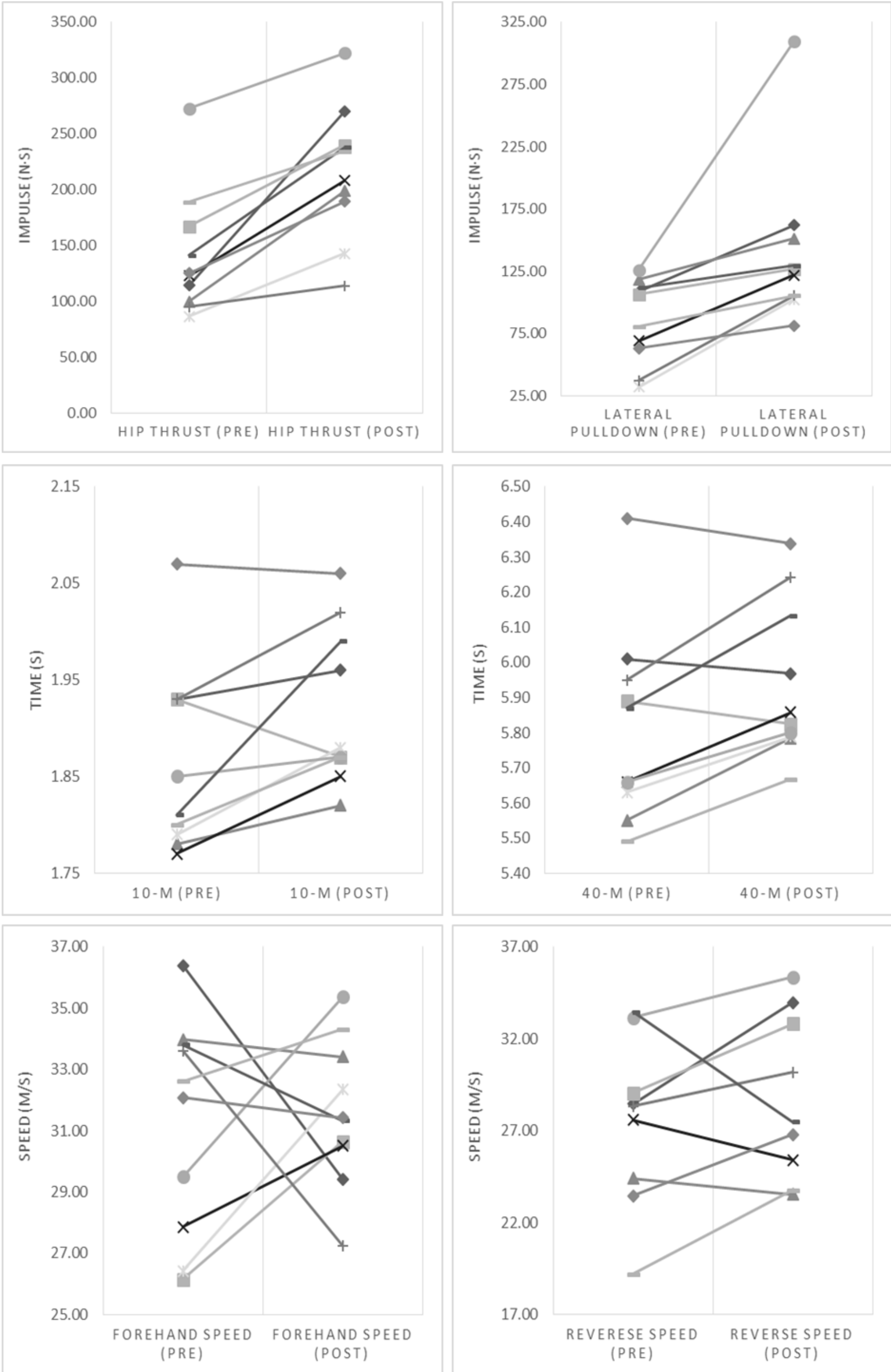

Figure 5. Individual pre and post data.
Presented are individual pre and post data for isometric hip thrust, isometric lateral pulldown, 10-m sprint time, 40-m sprint time, forehand release speed and reverse release speed

Discussion

The purpose of this study was to investigate whether a short-term training programme focusing on strengthening the hip and shoulder girdle would improve both sprint performance and ball release speed in field hockey players. The primary finding of this study was that the training intervention used was able to increase impulse in both strength assessments with a large ES noted for both the isometric hip thrust (ES = 1.21) and isometric lateral pulldown (ES = 1.46). In contrast to our hypothesis sprint time did not improve across any of the distances. The intervention was also only found to have a trivial to small effect on both forehand ball release speed (ES = 0.09) and reverse ball release speed (ES = 0.27).

With increases of 52.63% in the isometric hip thrust and 63.43% in the isometric lateral pulldown it would seem that the training intervention was particularly effective in increasing impulse production in the two aforementioned tests. As both these measures are novel it is difficult to compare to previous studies. In Contreras et al. (2016) study, which looked at the effect of six weeks of hip thrust training in youth (15.49 ± 1.16 years) rugby players, only a 29.95% increase was found in 3RM hip thrust post-intervention. While this resulted in a larger ES (ES = 2.20) the percent change was considerably less than what was found in this study. A study by Doan, Newton, Kwon, and Kraemer (2006) had collegiate level golfers perform a full body strength training programme, with three exercises for the latissimus dorsi, three times a week. Pre-post predicted lateral pulldown 1RM for the male participants was found to increase by 9.24% considerably less than found in the current study.

A recent meta-analysis of the effects of resistance training on physical performance in youth athletes by Lesinski, Prieske, and Granacher (2016) found that resistance training only had a moderate effect on muscular strength (standardised mean difference (SMD) interpreted using effect sizes = 1.09) far less than that found in this study. One possible reason for the markedly greater response in the present investigation is that the intervention employed included both hip thrusts and pull ups. It would follow that a greater training transfer effect would be expected in view of the dynamic correspondence between training modes and assessments employed. Another possible reason is that the participants were told to try and move the weights as quickly as possible on the concentric phase (even when the weight would not allow this). Behm and Sale (1993) previously reported that the intention to move explosively could potentially influence the velocity-specific adaptations elicited by strength training.

No improvements in group mean sprint times were found across any of the distance. Indeed mean sprint times showed an increase (Δ = +1.55-2.67%) and a small negative effect (ES = 0.31-0.57) observed. However, there was a great deal of heterogeneity in the findings when we examine individual participants. As illustrated in figure 4 three participants experienced a decrease in their sprint times with a 0.7%, 1.13% and 1.13% decrease occurring over the 40 m. The increase in the groups mean sprint time was surprising as Cronin, Ogden, Lawton, and Brughelli (2007) found in a review of the literature that improvements in maximal lower body strength of between 9-44% led to a decrease in sprint times by -0.9 to -4.3%. It was also determined that for recreationally trained athletes changes in squat strength of ~23% (the equivalent of a small to large effect ES = 0.7-2.0) were needed to see a trivial to moderate (ES = 0.22-0.95) change (~2.4%) in sprint times. The majority of the studies reviewed use the back squat. However, Contreras et al. (Contreras et al.) found that youth rugby players experienced possibly beneficial effects for 10 m sprint times (Δ = −1.06%; d = 0.55) and very likely beneficial effects for 20 m sprint (Δ = −1.70%; d = 1.14) after performing six weeks of hip thrust training. A more recent study by Bishop, Cassone, Jarvis, Turner, Chavda and Edwards (2017) found the opposite with collegiate athletes experiencing no significant improvement in sprint performance after eight weeks of hip thrust training despite having a similar increase in hip thrust 1 RM (29.95% vs 28.52%). The results of the current study would seem to be in agreement with those found by Bishop et al. (2017) as their hip thrust group also experienced a negative effect with the mean 40-m time increasing (Δ = 0.88%), though it was not large enough to be considered significant.

Two recent literature reviews have focused on the effect of resistance training in youth athlete populations. A meta-analysis by Lesinski et al. (2016) found that resistance training only had a small effect on sprint performance (SMD = 0.58). In a review by Behm et al. (2017) that looked at the effectiveness and power training on muscle strength and speed in youth populations they found that strength training had a moderate (SMD = 0.57) effect on sprint performance. However, this was when the data was analysed based on untrained participants. The authors found that the effect decreased was found to be small for trained youth participants (SMD = 0.45) and decreased even further for adolescent participants (SMD = 0.36). Taken together it would seem that the transference for strength to sprint performance is lower in trained youth than untrained youth and lower still in adolescents than children. Lesinski et al. (2016) noted that this lower transference to sprinting (and other secondary performance qualities) might be explained by the more complex nature of these qualities e.g. movement technique.

No significant effect was observed for either ball release speeds with the forehand shot demonstrating only a trivial positive effect (ES = 0.09) and the reverse shot a small positive effect (ES = 0.27). Due to the novel nature of this study it is difficult to tell whether or not the results recorded are normal, the closest comparison would be to golf studies examining ball speed. A study by Doan et al. (2006) found that after 11 weeks of strength training the male golfers (n = 10; age = 19.8 ± 1.7) increased their estimated 1 RM lateral pulldown by 9.24%, squat by 41.1% and club head speed by 0.61%. As in the current study the two strength measures were found to be statistically significant but the increase in CHS was not however, the authors stated that this increase was practically significant within golf. Therefore it stands that without the necessary field hockey research it is not possible to determine whether or not the increases in ball speed experienced for the forehand (1.2%) and reverse (5%) shots are of practical significance.

Limitations to the design of the study may have affected the results found. The sample size was small as access was limited to one field hockey team. Due to this study being novel in its use of youth field hockey players, and some of the measurements being recorded, it was decided that rather than reduce the sample size further a time series study design would be used. Another set of limitations, more technical, lie within the study and are the surface that the ball speed and sprints were performed on and the recovery status of the participants. Both the sprint testing and ball speed were performed outside on a synthetic water-based hockey turf. Whilst this was most appropriate from a validity point of view clearly environmental factors such as temperature, wind and rain cannot be controlled. As a synthetic water based pitch, the quality of the surface is quite consistent. However, there was heavy rain prior to the post test, which may have affected the outcomes of the testing. All players were wearing specialised hockey footwear with moulded studs designed for playing on synthetic pitches. Nevertheless, the heavy rain may have negatively affected shoe-surface interaction, and the temperature may also have been a factor. Similarly, the excess water may have affected ball speed times. Finally, due to scheduling and playing commitments the post-test session took part during the beginning of the hockey season, and all the participants involved had played a match earlier in the day before ball speed testing. Though the participants had a three hour recovery before testing it is not possible to determine what affect this would have had on their performance.

Due to the novelty of this study future research might look first at better understanding the effect of hip dominant training on sprint speed and in particular ball release speed in youth athletes. Secondly a better understanding is needed of the effect of shoulder girdle dominant training on both sprint speed and ball release speed.

Practical Applications

This is not only the first strength training study to be performed in field hockey players, whether youth or adult, but it is the first to look at the effect of strength training on sprinting and ball release speed; two important field hockey performance parameters. Though the results from the two performance parameters were less than ideal when looking at the individual results, taking the limitations into consideration and from what other studies have found it would seem as if there is merit in using more hip and shoulder girdle dominant exercises when trying to improve sprint and ball speed performance.

Chapter 6

Discussion, Practical Applications and Conclusions

Preface

As each experimental chapter provides its own individual discussion and practical applications section, the purpose of this chapter is to act as a brief synthesis of the main findings from the thesis, placing them in the context of the current literature. The goal of this section therefore is to enhance the current understanding of the relationship between the strength of the shoulder girdle and hip extensors and both sprint performance and ball release speed in field hockey as well as how strength training can affect these performance measures.

Discussion

Through the completion of all the stated aims, this thesis provides novel theories and data on the relationship between strength and sport-specific measures and the effect of strength training on these measures in youth field hockey players. Specifically, this thesis 1) established the reliability of both an isometric lateral pulldown and hip thrust; 2) ascertained the relationship between impulse, generated during a isometric lateral pulldown, and both sprint performance and ball speed; 3) ascertained the relationship between impulse, generated during a isometric hip thrust, and both sprint performance and ball speed; and 4) determined whether strengthening the hip extensors and shoulder girdle specifically would improve both sprint performance and ball speed in youth hockey players.

Despite field hockey being one of the world's most popular sports (Murtaugh, 2001) no research to date has examined the relationship between strength and sport-specific performance measures, or the effect of strength training on these measures. Therefore a broader review of the literature was conducted that looked at other sports with similar requirements. The review highlighted that while the relationship between lower body strength and sprint performance has been well established, the same was not true for upper body strength, in adult athletic populations the same has not been done for youth athletes. A limited number of studies in youth athletes seem to suggest that, in isoinertial assessments at least, there is a relationship between strength and sprint performance (Comfort et al., 2014). However, only two studies (Thomas et al., 2017; Thomas et al., 2016) have looked at the relationship between isometric assessments (the IMTP) and sprint performance in youth athletes with one reporting no relationship and the other reporting a relationship but only with 5-m sprint time. The review then examined whether similar relationships existed with ball striking performance which, unlike sprinting, had been found for both upper and lower body strength in both golf (Hellström, 2008; Thompson, 2002) and baseball (A. C. Fry et al., 2011). It was noted that the literature on ball striking sports was far less than sprinting, with the majority having been performed in golf, and that only golf had looked at isometric assessments (the IMTP) with both studies reporting moderate to large correlations (Leary et al., 2012; Loock et al., 2013). Though correlational studies can establish whether a relationship is significant and the strength of the relationship they do not determine whether it is causal. For sprinting it would seem that in youth there is a small but significant causal relationship, with studies having looked at the effect of lower, but not upper, body strength training on sprint performance (Lesinski et al., 2016). However, it was found that the magnitude of the effect was significantly determined by numerous factors including biological age and training status (Behm et al., 2017). One study of particular interest was that of Contreras et al. (2016) which used only one exercise, where most studies use multiple, and reported significant moderate improvements in sprint performance while the other group that used front squats reported small improvements. In comparison to sprinting there were no studies looking at improving ball striking performance in youth athletes. The limited available adult literature indicated that both lower an upper body strength training could increase ball striking performance in golf (Fletcher & Hartwell, 2004; Thompson & Osness, 2004). With only one study available in another sport it is difficult to tell whether these results are generalisable to other sports, though Kraemer et al. (2003) did find positive results in tennis players.

A considerable gap in the research was highlighted with there being a lack of literature on field hockey players, both senior and youth, correlational studies that examined the relationship between strength and sprint performance and finally studies investigating the relationship between strength and ball striking performance. Prior research has highlighted that in youth team sports whilst sprinting athletes develop force in ≤200ms (Rumpf et al., 2015) with similar results having been reported during a golf swing (Hume et al., 2005). Therefore study one looked to establish the reliability of an isometric lateral pulldown and hip thrust with early impulse measured over the first 250ms. Apart from a lack of variation in isometric assessments the lateral pulldown was chosen due to a number of studies showing strong correlations between similar patterns and CHS, (Hellström, 2008; Thompson, 2002; Wells et al., 2009). The hip thrust was then chosen due to its novelty and the current research not being clear on its ability to improve sprint performance with significantly different results being reported by the two studies having used it (Bishop et al., 2017; Contreras et al., 2016). For the isometric hip thrust participants sat on a box in the middle of a power cage, they were fixated using straps and chains in a semi-reclined position to the cage and then a lateral pulldown bar was hung from a strain gauge which in turn was attached to a fixated barbell. The angle that the participants were reclined to and the height that the bar was hung was determined using previous research that examined muscle activation during an isometric pulldown using a different piece of equipment (Park & Yoo, 2013). During the isometric hip thrust participants assumed a hip thrust position (Contreras et al., 2015), a dip belt and chains were used to attach them to a strain guage which in turn was attached to the floor. As no isometric assessments have been performed previously using a hip thrust the hip angle used was 40°± 10° of hip flexion. The study found both assessments reliable with the isometric lateral pulldown achieving a CV of 8.1% and an ICC of 0.9 whilst the isometric hip thrust reported a CV of 7.3% and an ICC of 0.97. With aim one being achieved and good reliability being reported for both assessments new data can now be collected on early impulse generation for both the shoulder girdle and hip extensor complex. The use of a strain gauge also allows for practitioners to more easily collect isometric data on athletes due to its lower price point and compact nature in comparison to a force plate.

Having established the reliability for both a shoulder girdle and hip extensor isometric assessment, the second experimental study looked to determine whether a significant relationship existed between them and two sport-specific performance measures (aims 2 & 3) in youth hockey players. Previous studies have explored the relationship between isometric assessments, predominantly the IMTP, and sprint performance (Thomas et al., 2015) in a variety of sports. However to date none have looked at field hockey despite elite male players having been found to spend up to 5% of match time in high-intensity striding and sprinting (Spencer et al., 2004). Therefore the first part of this study was to explore the relationship between both the isometric lateral pull down and hip thrust and sprint performance. The standard hockey sprint test protocol has players perform 40-m sprints (Reilly, 2001) therefore this distance was used for specificity with timing lights set at 10-m intervals to capture different split times. Insignificant ($p= >0.05$), trivial to small ($r= 0.061 – 0.152$) positive correlations were found between the isometric hip thrust and sprint times. Due to the novelty of the assessment it is difficult to determine whether these results are to be expected. Previous research using the IMTP has shown varying relationships to sprint performance, with Conlon et al. (2013) reporting large correlations in athletes from a arrange of sports and Jonathan et al. (2017a) reporting no significant correlations in elite soccer players. Similar to the hip thrust no significant correlations were found between the isometric lateral pulldown and sprint times over any distance. While still insignificant ($p= >0.05$) and trivial ($r= -0.055$ to -0.158) unlike the isometric hip thrust more traditional negative correlations were found between the isometric lateral pulldown and sprint performance. Though no previous studies have looked at the relationship between upper boy isometric strength and sprint performance, the lack of correlation is surprising. Prior findings (Mooney et al., 2001; Shin et al., 2013) suggest that latissimus dorsi EMG increases concurrently with gait velocity, therefore it would seem that as speed increases muscle recruitment also increases.

Bretigny et al. (2011) found that the effectiveness of shots in hockey can essentially be evaluated using three different variables: ball speed, accuracy in reaching the intended target and the time it takes to execute the shot (a shorter time limits the chance of the shot being intercepted). Given the importance of shooting to the sport, the second sport-specific performance variable was ball speed. One of the most common shots due to its power is the forehand shot which, because of this, is predominantly used for shooting at the goal and long range passing (Bretigny et al., 2008). The second shot used in the study was the reverse shot. This was selected due to the greater technical ability needed to execute it and because of it kinematic similarity to the tennis backhand which research indicates shows a high level of latissimus dorsi activation (Rogowski et al., 2011). Ball speed testing was undertaken on a standard synthetic hockey pitch. In a game context these shots are made while a player is in motion. However, to limit any confounding factors regarding the effect of each participant's individual speed of approach, each participant was allowed to take only two steps before executing the shot. A hockey ball was placed perpendicular to the goal on the shooting circle and a radar gun placed behind the goal and directed towards the ball. Significant moderate to large positive correlations were found between the isometric hip thrust and both forehand (r= 0. 0.68, p= 0.000) and reverse (r= 0.47, p= 0.025) ball speeds suggesting that those who produced the most impulse in the hip thrust had the highest ball release speed for both shots. Due to the lack of literature surrounding field hockey it is difficult to tell whether the results found are common. While they only share certain kinematic similarities Loock et al. (2013) found significant correlations (r= o.558, p= 0.011) between the IMTP and CHS in golf, however Leary et al. (2012) found none. For the isometric lateral pulldown significant moderate positive correlations were found with forehand ball speed (r= 0.42, p= 0.046) but not with reverse ball speed (r=0.27, p= 0.219). Though no studies have looked at isometric upper body measures a study by Wells et al. (2009) found that the pull-up had a very large correlation (r= 0.8, p= ≤0.0001) with CHS when testing the Canadian National Golf Team. The only other similar movement to the reverse shot that has been researched is the tennis backhand. While no correlations have been established an EMG of the movement found moderate activation of the latissimus dorsi during the acceleration phase (Ryu et al., 1988) suggesting that its strength would be relevant to the performance of the shot. In summary the study found that there was no significant relationship between the strength measures and sprint performance over any distance. For ball speed however, significant moderate to large correlations were found between both strength measures and forehand ball speed but only the isometric hip thrust had a significant relationship to reverse ball speed.

Though significant correlations were established between the isometric test and some of the performance measures this did not imply causation thus, the third experimental study looked to demonstrate this (aim 4). The design used was that of a five week pre-post single group study. Participants completed two fully supervised strength training sessions a week and were required to maintain their usual field hockey practice. They were also told to refrain from any additional resistance or plyometric training. All the participants were youth male field hockey players who represented their secondary school team. The resistance training protocol prescribed during the study consisted of the barbell hip thrust, lateral pulldown and other shoulder girdle and hip extensor dominant exercises such as a dumbbell step up. For each exercise participants were given a repetition range and told to try and achieve the upper end of the range with good form before increasing the weight used. Participants were required to complete all the previously outlined tests before and after the training intervention. The primary finding of this study was that the training intervention used was able to increase impulse in both strength assessments with a large effect size noted for both the isometric hip thrust (ES = 1.21) and isometric lateral pulldown (ES = 1.46). A recent meta-analysis of the effects of resistance training on physical performance in youth athletes by Lesinski, Prieske, and Granacher (2016) found that resistance training only had a moderate effect on muscular strength (standardised mean difference (SMD) interpreted using effect sizes = 1.09) far less than that found in this study. Two potential reasons for this result are firstly the use of the hip thrust and pull up in the intervention, due to their similarities with the isometric assessment there might have been a greater transfer of training effect than usual. Another possibility is that participants were told to try and move the weight as quickly as possible which could have influenced the velocity-specific adaptations of the training as research by Behm & Sale (1993) has found that the intent to move the weight quickly can do this.

For sprint performance no improvements in group mean sprint times were found across any of the distance. Indeed mean sprint times showed an increase (Δ = +1.55-2.67%) and a small negative effect (ES = 0.31-0.57) was observed. However, a great deal of heterogeneity could be seen in the findings when individual participant results were examined. Three participants did experience a decrease in their sprint times with a 0.7%, 1.13% and 1.13% decrease occurring over the 40 m. Initially the result were surprising as Contreras et al. (2016) found that youth rugby players experienced possibly beneficial effects for 10 m sprint times (Δ = -1.06%; d = 0.55) and very likely beneficial effects for 20 m sprint (Δ = -1.70%; d = 1.14) after performing six weeks of hip thrust training. More recently though a study by Bishop et al. (2017) found the opposite, with collegiate athletes experiencing no significant improvement in sprint performance after eight weeks of hip thrust training despite having a similar increase in hip thrust 1 RM (29.95% vs 28.52%). The results of the current study would seem to be in agreement with those found by Bishop et al. (2017) as their hip thrust group also experienced a negative effect with the mean 40-m time increasing (Δ = 0.88%), though it was not large enough to be considered significant. Furthermore a review by Behm et al. (2017) that looked at the effectiveness and power training on muscle strength and speed in youth populations found that strength training only had a small (SMD = 0.36) effect on sprint performance in trained adolescent participants.

After the intervention no significant effect was observed for either the forehand shot (ES = 0.09) or reverse shot (ES = 0.27). Considering the novelty of the assessments used it is difficult to know whether the results recorded are normal especially since the lack of literature. An interesting concept though is that of the difference between a result being statistically significant and practically significant. Doan et al. (2006) found that after 11 weeks of strength training male golfers increased their estimated 1 RM lateral pulldown by 9.24%, squat by 41.1% and club head speed by 0.61%. Similarly to this study the increases in strength were considered statistically significant but the CHS was not however, the authors stated that the increase in CHS was practically significant within golf. Therefore it stands that without the necessary field hockey research it is not possible to determine whether or not the increases in ball speed experienced for the forehand (1.2%) and reverse (5%) shots are of practical significance.

Limitations and delimitations of thesis

As with all research this thesis features certain methodological constraints which are important to consider when interpreting the reported results. Those considered to be the key constraints are outlined below with rationale given:

1) During the training intervention due to scheduling and player commitments the post-test session took part during the beginning of the hockey season. This meant that the participants involved in the intervention had to play a match earlier in the day of the ball speed test. Though the participants had a three hour recovery before testing it is not possible to determine what affect, if any, this would have had on their performance. If the athletes were fatigued this could explain the results of the ball speed test, however as some did experience an improvement it is difficult to tell.
2) The lack of a positive effect of the training intervention on sprint performance may be explained by the length of the study period. With many of the studies reviewed lasting 6-8 weeks, and others longer, (Behm et al., 2017) five weeks might be too short a duration to expect changes in sprint performance. In Lesinski et al. (2016) meta-analysis of dose-response relationship of resistance training on physical performance markers in youth athletes it was

found that training period of ≥23 weeks were needed to see moderate improvements in agility (SMD_{wm}=1.31) and with shorter periods experiencing a less beneficial effect. For vertical jump height a training period of 9-12 weeks appeared to be the most effective, leading to moderate improvements (SMD_{wm}=1.20). While dose-response relationships results for sprint performance were not reported and these movements are not the same, it does suggest that performance variables with a more complex nature might require longer for improvements to be seen.

3) Related to the previous point is the concept of specificity of training which states that the adaptations to training are specific to its nature (Young, 2006), and therefore a concurrent sprint training programme, as used in some other studies, may have elicited positive changes in sprint performance. The rationale for not having a concomitant sprint programme was due to the athletes already sprinting as part of their usual training and the study wanting to examine the effects of resistance training only on sprint performance as was done in the two other hip thrust studies (Bishop et al., 2017; Contreras et al., 2016).
4) The sample size was small as access was limited to one field hockey team. Due to this study being novel in its use of youth field hockey players, and some of the measurements being recorded, it was decided that rather than reduce the sample size further, to create a control group, a small scale single-group pretest-posttest study design would be used (Salkind, 2010). By using this style of study design the emphasis is placed on looking at the nuances of individual response, rather than on p values and possible population implications, as there is an increased chance of randomness in the findings.
5) Both the sprint testing and ball speed were performed outside on a synthetic water-based hockey turf. Whilst this was most appropriate from a validity point of view clearly environmental factors such as temperature, wind and rain cannot be controlled. As a synthetic water based pitch, the quality of the surface is quite consistent. However, there was heavy rain prior to the post test, which may have affected the outcomes of the testing. All players were wearing specialised hockey footwear with moulded studs designed for playing on synthetic pitches. Nevertheless, the heavy rain may have negatively affected shoe-surface interaction, and the temperature may also have been a factor. Similarly, the excess water may have affected ball speed times.

Conclusions

For this thesis it was determined that strengthening the shoulder girdle and hip extensors specifically may increase ball speed but not sprint performance in youth hockey players. These results confirm those found in the correlational study where impulse, generated by the shoulder girdle and hip extensor, was found to have a positive correlation to ball speed. The lack of a meaningful correlation with and improvement in sprint performance was initially surprising. However, potential reasons for this may lie in novelty of the intervention and the potential difference in sprint kinematics for field hockey in comparison to other sports. Given the lack of data with regards to field hockey this thesis represents an initial attempt to try and improve sport-specific performance through resistance training. When looking to improve ball speed practitioners should work to increase both hip extensor and shoulder girdle strength. The isometric hip thrust and lateral pulldown also represent a reliable way for practitioners to track potential improvements in ball speed given the moderate to large positive correlations found.

Practical applications and future research

- The isometric hip thrust and isometric lateral pulldown assessments both demonstrated high inter-session reliability for impulse at 0-200ms and therefore can be used as either a baseline assessment in research or as part of a structured monitoring program by practitioners. Future research should look at both the use of heavy-duty ratchet straps for attachment to load cell, allowing for joint angles to be easily adjusted, and what hip angle allows for the largest force production.
- This is not only the first strength training study to be performed in field hockey players, whether youth or adult, but it is the first to look at the effect of strength training on sprinting and ball release speed; two important field hockey performance parameters. Though the results from the two performance parameters were less than ideal when looking at the individual results, taking the limitations into consideration and from what other studies have found it would seem as if there is merit in using more hip and shoulder girdle dominant exercises when trying to improve sprint and ball speed performance.
- More research is needed in field hockey to quantify kinematic models of sprinting and hitting and what exercises have strong correlations to these movements. Future research should first focus on developing a better understanding of the key muscles utilised in field hockey sprinting and shooting through the use of EMG. Once the muscular demands are better

understood then other correlational studies can be carried out to determine the extent that the strength of these muscles are important. Training studies can also be implemented to see whether increasing muscular strength in specific areas has a significant impact on sprint times and ball speeds in hockey players.

- Due to the novelty of study three future research might look first at better understanding the effect of hip dominant training on sprint speed and in particular ball release speed in youth athletes of other sports. Secondly a better understanding is needed of the effect of shoulder girdle dominant training on both sprint speed and ball release speed.

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Appendices

Appendix 1. Ethics approval and amendment form

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www.aut.ac.nz/researchethics

20 October 2016

Nigel Harris
Faculty of Health and Environmental Sciences
Dear Nigel

Ethics Application: **16/358 The effect of shoulder girdle and hip complex strength training on sprint and hitting performance in field hockey players.**

Thank you for submitting your application for ethical review. I am pleased to advise that the Auckland University of Technology Ethics Committee (AUTEC) approved your ethics application at their meeting on 17 October 2016 subject to the following conditions:

1. Reconsideration of how recruitment will take place, given the responses in sections C.3.5.1 and H.4. AUTEC advises that it is appropriate for those interested to make contact directly with the researcher as opposed to the club managers suggesting players that have shown an 'interest';

I will amend my recruitment process so that individual players contact me directly rather than via their coaches or team managers.

2. Provision of the recruitment advertisement and or email;
3. Clarification of the inconsistency between section C.3.2 and C.3.3.1 of the application with regards to participant numbers;

The minimum number of players that I would like to recruit is 22 due to statistical reasons, however to improve the quality of results if additional players want to take part I am willing to accept up to a total of 40 players

4. Confirmation in section D.1 that on completion of the study that the group's results sent to participants will be de identified;

Yes, at the end of the study each player will receive their individual results however they will also receive the de identified results of all the other players that took part in the study.

5. Reconsideration of offering participants a token of appreciation;

As the Master's budget is only $750, and the testing and training offered as part of the study will improve sporting performance, any other incentive or form of appreciation was considered unnecessary.

6. Inclusion of an additional bullet point in the Consent Form about performance enhancing substances exclusion;

Please see attached form for amendments.

7. Amendment of the Information Sheet as follows:
    a. Inclusion in the section on costs the total time commitment (28 hours);
    b. Inclusion of point 3 above and confirmation of confidentiality and an assurance of de-identification.

Please see attached form for amendments.

Please provide me with a response to the points raised in these conditions, indicating either how you have satisfied these points or proposing an alternative approach. AUTEC also requires copies of any altered documents, such as Information

Sheets, surveys etc. You are not required to resubmit the application form again. Any changes to responses in the form required by the committee in their conditions may be included in a supporting memorandum.

Please note that the Committee is always willing to discuss with applicants the points that have been made. There may be information that has not been made available to the Committee, or aspects of the research may not have been fully understood.

Once your response is received and confirmed as satisfying the Committee's points, you will be notified of the full approval of your ethics application. Full approval is not effective until all the conditions have been met. Data collection may not commence until full approval has been confirmed. If these conditions are not met within six months, your application may be closed and a new application will be required if you wish to continue with this research.

To enable us to provide you with efficient service, we ask that you 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.

I look forward to hearing from you,

Yours sincerely

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Kechi Anyadike-Danes , kechi.anayadike-danes@aut.ac.nz; Paul Gamble

AUTEC Secretariat

Auckland University of Technology

D-88, WU406 Level 4 WU Building City Campus

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www.aut.ac.nz/researchethics

31 October 2016

Nigel Harris
Faculty of Health and Environmental Sciences

Dear Nigel

Re Ethics Application: **16/358 The effect of shoulder girdle and hip complex strength training on sprint and hitting performance in field hockey players.**

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

Your ethics application has been approved for three years until 26 October 2019.

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 through http://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 26 October 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 26 October 2019 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.

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,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Kechi Anyadike-Danes, kechi.anayadike-danes@aut.ac.nz; Paul Gamble

Participant Information Sheet

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Date Information Sheet Produced:

21/09/16

Project Title

The effect of shoulder girdle and hip complex strength training on sprint and hitting performance in field hockey players

An Invitation

You are invited to be a part of a research project that is looking at the role of the shoulder girdle and hip extensors in sprinting and hitting performance. It is important to note that if you do choose to take part in this research that your involvement is completely voluntary and you can choose to withdraw at any point.

What is the purpose of this research?

In elite male field hockey players five percent of match time is spent in high-intensity striding and sprinting however so far no studies have examined the effect of strength training on sprint performance in this cohort. In shooting it is thought that the effectiveness of any shot is determined by three different parameters: ball speed, accuracy in reaching the goal or intended teammate and the movement duration (a shorter time limits the opportunities for an opponent to intercept). However, like sprinting no studies have examined the relationship between strength and ball speed or the effect that strength training has on it. The purpose of my research is to firstly investigate the relationships between sprint speed, ball speed, shoulder girdle and hip complex strength in hockey players. After which I will look at the effects of eight weeks of specialised strength training, targeting the shoulder girdle and hip complex, on sprint speed and ball velocity in hockey players. This research will go towards the completion of a dissertation as part of the Master of Sport and Exercise programme with AUT.

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

You were invited to be part of this research as you have either responded to an advertisement of this study or have been approached in person and expressed your interest to be involved.

In order to be a part of this study you will need to meet the following criteria:

- Male
- 16 years or older
- Currently playing at national level or higher
- Injury free
- Are not, or have not, used performance enhancing substances.

If you do not understand the above criteria please contact the primary researcher for more information. Additionally if you do not meet the above criteria then unfortunately you will not be able to participate in this study.

What will happen in this research?

This study involves being a part of an 8 week training intervention. You will be placed in one of two groups; traditional strength training group or specialised strength training group. Initially you will need to complete four performance tests, the first two will be strength tests, the third will be a sprint test and the fourth will measure how hard, and therefore fast, you can hit a hockey ball. This assessment procedure should take no longer than 2 hours and will take place at AUT, Millennium. Following this you will be given an 8 week strength training protocol to carry out 3 times per week.

What are the discomforts and risks?

You will be required to perform sub-maximal and maximal exercise pre, during and post intervention and as a result you will experience a short duration of discomfort for these maximal tests. Being an experienced athlete, these tests will be similar intensity to that of your regular training.

How will these discomforts and risks be alleviated?

Experienced coaches will be monitoring throughout the intervention and will ensure that you are not putting yourself in danger. In addition you may choose to withdraw from the study up until the end of the 8 week data collection.

What are the benefits?

The benefits of taking part of this study will be the expert coaching during the intervention by New Zealand sprint coach Paul Gamble. You will be contributing to the research of strength training in field hockey which will help improve the design of training protocols for sprinting and hitting. This research will go towards the completion of a thesis as part of the Master of Sport and Exercise programme with AUT.

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?

All data that is collected will only be available to the research team. No information identifying you as a participant in this research will be included in any of the research reports or publications as all your information will be de identified.

What are the costs of participating in this research?

The only cost for your participation in this research is your time. If you choose to participate you will take part in two 2-hour testing sessions and need to commit to an 8 week training period, this will consist of three-1 hour strength training sessions per week. In total the time commitment for the entire period of the study is 28 hours. All testing will take place at AUT Millennium, 17 Antares Place, Mairangi Bay, Auckland.

What opportunity do I have to consider this invitation?

If you would like to take part in this research it is asked that you do so within two weeks of receiving this information.

How do I agree to participate in this research?

In order to take part in this research you will need to first contact the primary researcher (details at the bottom of this form). You will need to complete a consent form which will be provided to you once you have expressed your interest. Once the consent form has been completed the primary researcher will be in contact with you to commence the process. However, due to health and safety reasons the maximum number of players that can take part in the study is 40 therefore once this number has been recruited no other players will be able to be accepted onto the study.

Will I receive feedback on the results of this research?

You will have the option of receiving a summary of the findings from the research with each players personal information de identified. Once these are available you can have them sent to your postal address as a hard copy or receive an electronic copy 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, *Paul Gamble, paul.gamble@aut.ac.nz, (09) 921-7057*.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Kechi Anyadike-Danes, kechi.anyadike-danes@aut.ac.nz*, 0279073564*

Project Supervisor Contact Details:

Paul Gamble, paul.gamble@aut.ac.nz, *(09) 921-7057*

Approved by the Auckland University of Technology Ethics Committee on 31/10/16, AUTEC Reference number 16/358.

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Consent Form

Project title: The effect of shoulder girdle and hip complex strength training on sprint and hitting performance in field hockey players

Project Supervisor: *Dr Paul Gamble*

Researcher: *Kechi Anyadike-Danes*

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 21th September 2016
- ○ 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 current injury or illness that impairs my physical or mental performance to perform the tasks required nor am I outside the limits of the required age range of 18 to 35 years.
- ○ I have not nor am I currently using a performance enhancing substance (WADA 2016)
- ○ If I withdraw, I understand that all relevant information will be destroyed.
- ○ I agree to provide physical effort to the best of my ability throughout the testing
- ○ 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):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 26th October 2016

AUTEC Reference number 16/358

Note: The Participant should retain a copy of this form