The Relationship Between Maximal Strength and Performance Measures: A Correlational Study.

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Abstract

The aim of this study was to identify if correlations existed between maximal strength in three different compound movements involving hip extension and the results of various performance tests which are potentially relevant to team sports. The three movements were the back squat, hip thrust and deadlift. The performance tests involved a sprint test, change of direction test, medicine ball test and jump tests.

Previous studies have identified correlations between maximal squat strength and performance measures in resistance trained populations. However, there is little previous research in the untrained population on hip thrust and deadlift strength as a predictor of performance which our study aims to address. It is important for coaches to evaluate performance determinants in athletes so that they can tailor coaching sessions in a way which may improve overall performance.

We used an untrained population in our study as the hip thrust is a non-technical movement which is easy for beginners to learn. This could identify if the hip thrust may be a useful movement for beginners to weightlifting due to the limited previous research, when compared to the more complicated squat and deadlift movements.

31 male volunteer participants took part in one repetition maximum (1RM) tests and performance tests. Statistical analysis was carried out on SPSS software using Pearson's correlation on all relevant variables. A Bonferroni correction calculation was then performed meaning that only correlations with an α-value less than 0.0011 would be accepted as significant.

There were negative correlations between the 40-yard dash time and relative squat strength as well as relative hip thrust strength whilst relative hip thrust strength also provided negative correlations between the two split times recorded. There were negative correlations observed between relative hip thrust strength and broad jump distance, and also between change of direction time and medicine ball rotational scoop toss distance. There were no correlations observed between vertical jump height and any other variables.

The present findings suggest that increased strength in both the back squat and hip thrust movements could be related to increased sprint performance and, in the case of the hip thrust movement, increased acceleration performance.. The relationship between hip thrust strength and broad jump distance also suggests the importance of strength in this lift for jump performance. A strength coach may look to prescribe a training programme employing both squat and hip thrust to potentially improve performance through increasing strength in both movements.

Key Words: maximal strength, performance, squat, hip thrust.

Contents

Introduction

Importance of performance measures in sport

A number of key variables seem to be important in athletic performance, these include sprinting and jumping. It is, therefore, important to understand the role of performance measures in predicting athletic performance in a competitive setting. It could then be possible for a strength coach to employ a resistance training programme aimed at potentially improving performance in such tests to improve sporting performance.

For example, Fry and Kraemer (2008) studied relationships between performance tests and playing ability in American football. This study was on college players and attempted to find differences in performance test measures between players in different divisions and between starters and non-starters. It was found that players who played at division one level were significantly better in the 40-yard dash test and vertical jump than the players in division two or three. The same significant differences were found between players which were considered good enough to start matches at their position and players who were not.

Further to this, Sierer et al. (2008) studied the performance in NFL combine tests of drafted and undrafted players and looked to discover the differences between the groups. Drafted players are college American football players deemed to be of a high enough quality by professional teams to play in the NFL while undrafted players are not considered good enough to play professionally. Once the players were split into groups corresponding with playing position, it was found that the drafted players performed better in the 40-yard dash in every position group but only the drafted group containing the faster and more athletic wide receivers and defensive backs performed better in the vertical jump test and change of direction test compared to the slower, less athletic linemen. In ice hockey, Farlinger et al. (2007) assessed the relationship between on-ice performance and performance in off-ice tests. They found that off-ice 30-metre sprint time and 3-hop broad jump both correlated with skating speed and ability on the ice. All team sports considered in these studies are similar in their speed and use of the lower limbs in order to succeed. Collectively these studies suggest that a player's ability to sprint and jump are key determinants of performance. Therefore, improving sprint and jump performance through strategic training may improve sporting performance.

All team sports considered in these studies are similar in their speed and use of the lower limbs in order to succeed. It might be suggested that increased strength in the lower limbs and increased speed are beneficial for performance.

Relationship between performance tests and muscle groups used

Figure 1 – Position of lower limb muscle groups

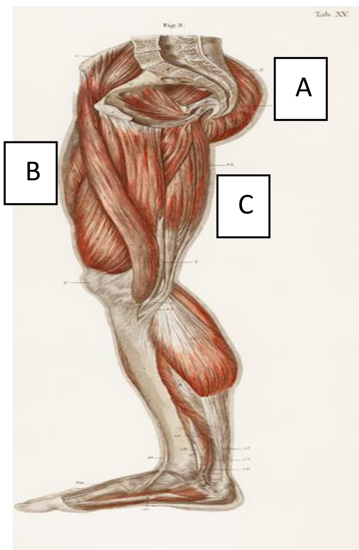

Figure 1: Diagram showing the position of the hip extensor muscles (A), knee extensor muscles (B) and knee flexor muscles (C).

It is important to understand which muscle groups are recruited during different performance tests and how this is transferable to the muscle groups used during games. This knowledge can be used to prescribe a training programme aimed at improving strength in those muscle groups with the subsequent aim of improving performance for competition. The compound movements, movements which incorporate the use of multiple joints and multiple muscle groups at once, used in the current study all incorporate the hip extensors but vary in the degree to which the other prime movers are used. Therefore, we will consider the strength of the hip extensors and flexors and the knee extensors and flexors and their possible contribution to performance outcomes.

The muscles which make up the knee flexors and hip extensors and the force which they can produce may be pivotal in sprint and jump performance. Nesser et al. (1996) assessed which physiological variables determine 40-metre sprint performance. They found that there are a range of predictors of 40-metre sprint speed. As expected, 10-metre sprint speed correlated with 40-metre sprint speed suggesting that starting the sprint quickly and maintaining acceleration throughout the full 40-metre sprint is highly important when sprinting. Also correlating with 40-metre sprint speed was the strength of hip extensors and knee flexors as well as the contractile properties of each and the force each can produce. It is thought that individuals with knee flexors and hip extensors that can produce greater force will be able to accelerate quicker through the propulsion of the body in a forward direction. This is similar to the hypothesis developed by Contreras et al. (2017) that greater horizontal force production would translate to greater acceleration. This could suggest that due to the similar nature of the horizontal movement in the acceleration phase of a sprint and the horizontal concentric contraction of the hip thrust, maximal hip thrust strength can be a predictor of 10-metre sprint time and subsequently 40-metre sprint time. It could also be suggested that due to the greatest activation of the hip extensor muscles during the hip thrust movement (Andersen et al., 2017), a correlation may be expected between maximal hip thrust strength and 40-yard dash time which is the test used in our study, particularly in the acceleration phase.

Also, providing more information on force production whilst sprinting is a study by Brughelli et al. (2011). During a study involving professional Australian Football players running at speeds increasing incrementally, it was found that horizontal force production increased significantly as speed increased. Knowledge of increased horizontal force production throughout the hip thrust movement provides a suggested link between increased performance in both the hip thrust movement and a maximal sprint effort.

The study by Nesser et al. (1996) did however include twenty athletes which may not be comparable to results obtained in our study within an untrained population. Contreras et al. (2017) and Andersen et al. (2017) also examined a population different to our untrained population where adolescent athletes and recreationally trained individuals were used.

I It may be the case that the hip flexor strength, together with hip extensor strength is also a predictor of sprint speed due to earlier research (Guskiewicz, Lephart and Burkholder, 1993). This study examined the relationship between 40-yard sprint speed and hip extensor and flexor strength when measured from a functional standing position. The results suggest that there is a strong correlation between sprint speed and the peak torque relative to body mass in both the hip flexors and extensors.

It appears the hip extensors and knee flexors are critical, but what of the knee extensors? Previous research involving the relationship between 40-yard sprint speed and isokinetic strength measures deduced that there is no significant correlation between sprint speed and knee extension strength suggesting that another factor may be responsible for sprint performance (Kin-Isler et al., 2008). Knee extension is the action performed during the extension of the lower limb lever with the knee being the fulcrum and is completed when the leg is completely straight. It is expected that increased strength in the knee extensor muscles such as the rectus femoris and vastus lateralis will enable an individual to perform knee extension under greater loads. These data indicate that strength in the hip extensors and knee flexors is most important for sprint performance and that exercises activating and potentially improving strength in these muscles may be more useful for improving performance outcomes.

Results of the study by Kin-Isler et al. (2008) may be more comparable to results in our current study as subject numbers were similar (n=28) and although American football players were used, they were playing at an amateur level. Gusciewicz, Lephart and Burkholder. (1993), on the other hand, had larger subject numbers (n=41) and they were performing at a higher level as trained athletes.

Jump performance is also important for overall sporting performance though, therefore we will consider predictors of jump performance. Tsiokanos et al. (2002) studied the relationship between vertical jumping performance and the isokinetic force produced by the hip extensors, knee extensors and ankle plantar flexors. They found that there was a moderate to strong correlation between jumping performance and hip extensor torque and knee extensor torque, particularly when compared relative to body weight. They also found, however, that there is no significant correlation between jumping performance and ankle plantar flexors peak torque suggesting that although hip and knee extension are key components of jumping, ankle strength does not affect such performance. A similarly interesting finding by Nesser et al. (1996) is that the stronger ankle plantar flexion, the slower the 40-metre sprint time which is potentially consistent with the findings by Tsiakanos et al. (2002) as there appear to be no positive implications of stronger ankle plantar strength on sprinting and jumping performance. This study again is similar in size (n=22) and subject training status.

Previous research examining which muscle groups are activated to the greatest extent during different compound movements can then be used to prescribe a training programme that will potentially improve strength in those muscle groups. This could, therefore, improve performance measures such as sprinting and jumping through a knowledge of muscles used during performance tests. Therefore, we will next consider which exercises are responsible for activating, and potentially improving strength in, various muscle groups.

Muscle groups used during movements

Studies on electromyography (EMG) activity during resistance exercise provide a better understanding of the muscles activated to the greatest extent during the back squat, deadlift and hip thrust. Isear et al. (1997) studied the pattern of muscle recruitment during an unloaded squat exercise through EMG analysis. The EMG activity during the lift suggested that quadriceps activation was much greater than hamstring activation although the fact that the squat was unloaded may have affected the muscle activation compared to a loaded squat. The loaded squat was studied by Robertson et al. (2008) in a similar study design where they attempted to determine the role of various lower limb muscles during a full depth loaded squat. . They found that the gluteus maximus and the vastus lateralis are the main muscles responsible for stabilising joints during the descent phase. The majority of force during the ascent of the squat is produced by the hip extensors, such as the gluteus maximus again, followed by the ankle plantar flexors and the knee extensors. The initial power produced immediately after the hip rise from the bottom of the squat is initiated by these muscles while the hip extensors and more specifically the gluteus maximus are responsible for keeping the hip rising during the latter phase of the squat until a standing position is achieved. These data indicate that the squat may therefore be a key exercise for activating and strengthening the hip extensors, knee extensors and ankle plantar flexors.

Many previous papers studying the EMG activity during the deadlift have been comparing the lift to other lifts such as the squat as mentioned previously in the studies by Wright et al. (1999) and Andersen et al. (2017). A study of note is that of Camara et al. (2016) comparing the muscular activity of a straight bar deadlift and a hexagonal bar deadlift. The straight bar deadlift as used in our study is performed with a straight barbell placed in front of the individual lifting whereas during the hexagonal bar deadlift the individual steps into the hexagonal bar with their arms by their sides to grip the handles (Figure 2). The findings were similar to that of Andersen et al. (2017) where the straight bar conventional deadlift produced the greatest activity in the biceps femoris as predicted. The hexagonal bar deadlift did, however, produce greater vastus lateralis activation than the straight bar variation which is what would be expected during a squat. Andersen et al. (2017) suggested that the hexagonal bar deadlift is a similar exercise to the squat which may explain the similarities in the muscles activated throughout the two movements.

Figure 2 – Depiction of deadlift variations

Figure 2: The image on the left depicts a conventional straight bar deadlift as used in our study with the image on the right depicting a hexagonal bar deadlift.

Andersen et al. (2017) also compared the use of different muscle groups during the hip thrust to the two deadlift variations. They found that there was greater activation in the gluteus maximus, of the hip extensors, than in the barbell deadlift, although the barbell deadlift did result in greater activation of the biceps femoris muscle, of the knee flexors. The large gluteus maximus activation was also seen in a previous study by Contreras et al. (2015) when comparing the hip thrust to the squat. It was noted, however, that the hip thrust did also result in greater activation of the knee flexor muscles when compared to the squat. These findings collectively indicate that the squat and hip thrust both elicit large activation of the hip extensors whilst it is the knee flexors which are activated to the greatest extent in the deadlift. Nevertheless, the hip thrust movement does still produce activation of the knee flexor muscles.

All studies cited on the muscle groups activated during the movements used in our study used a trained population and therefore may elicit results non-transferable to the population used in our study. However, due to the fact EMG analysis was used to identify which muscles were activated throughout different movements rather than to which extent each muscle was recruited, it can be hypothesised that results would be similar in any population group.

Further to the relationship between muscle groups used during performance tests and compound movements, relationships can be studied between the performance tests themselves. Correlations found between results in different performance tests may indicate similar muscle groups being used, such as the hip extensors, knee extensors and knee flexors, and training programmes can look to improve strength of these muscles and potentially improve performance.

Relationship between measures of strength and performance tests

Various previous studies have examined the use of different tests such as strength-power tests and jump tests as predictors of sprint performance. The use of strength-power tests has provided evidence that the ability to produce force quickly is a determinant of sprint performance. This was evidenced through the observation of the time to reach 60% MVC and performance during a 30cm drop jump test (Bissas and Hevanetidis, 2008). Further tests used as predictors of sprint performance are jump kinetic tests, as used by Maulder et al. (2008). Performance in jump tests directly correlate with performance in sprint tests and, in this case, better results in both squat jump and countermovement jump tests correlated with better results in a 10-metre sprint test. These data are in accordance with the conclusions drawn by Wisloff et al. (2004) where jump performance correlated with the 10-metre split of a 30-metre sprint. They also suggested that greater half squat 3RM correlated with both sprint and jump performance.

However, not all studies agree with the literature suggesting a relationship exists between sprint and jump test results. Studies by Meylan et al. (2009) and Kukolj et al. (1999) observed the reliability of jump tests and of basic strength and power tests respectively as predictors of sprint performance. Both studies found that the tests used were poor predictors of sprint performance and could not be used reliably for this purpose. Meylan et al. (2009) did however use single leg vertical and horizontal jumps instead of the conventional double leg technique used in other studies referenced which could potentially explain the disparity. Other data collected in the study looked to identify correlations between the single leg jump tests and a change of direction test which was also not statistically significant. These data are surprising considering the requirement of unilateral strength in change of direction tasks. It also conflicts with more recent research which suggested that unilateral jump tests were better predictors of sprint speed over 10 and 25 metres when compared to bilateral jump tests (MCCurdy et al., 2010). Collectively these studies suggest that it is hard to determine exactly whether there is a relationship between sprint and jump tests. Some findings may be due to the design of the jump tests and other types of jump test may offer alternative results.

The test-retest reliability of performance tests used within our study are strong with Glaister et al. (2009) finding a coefficient if variance (CV) of 1.1%-1.3% for the 40-yard dash test following a familiarisation test. Also following a familiarisation test, Stewart et al. (2012) found the 5-10-5 change of direction test to have a CV of 1.95%-2.4%. Both jump tests used also have a strong test-retest reliability with the vertical jump test and horizontal jump test having CV's of 2.8% and 2.4% respectively (Markovic et al. (2004). There has, however, been no previous test-retest reliability discovered for the medicine ball scoop toss as it is a scarcely used performance test.

Isokinetic tests

The use of isokinetic tests is the most accurate way to measure strength in particular muscle groups when compared to other methods such as 1RM tests. The main limitation with isokinetic strength as a measure of muscular strength is the fact that isokinetic dynamometers are not freely available to all coaches and performance analysts (Levinger et al. 2009). Due to this, coaches can use 1RM tests in various different movements such as the squat, deadlift and hip thrust in order to make a prediction about strength in different muscle groups. For example, an individual with a greater squat 1RM may be expected to have greater isokinetic strength in the hip and knee extensor muscles compared to an individual with a lower squat 1RM. The predictions made can then be translated to expectations of performance measures and incorporated into programming decisions.

Previous research on squat

After examining the relationship between the muscle groups used in the performance tests and during compound movements it is important to acknowledge previous research which has already attempted to find correlations between strength in these movements and performance measures. This can help with the understanding of strength of particular muscle groups in relation to good performance measures and suggest a training programme which may be the most beneficial for improvement.

When looking at potential improvements to performance, Styles et al. (2016) discovered that the six-week squat training programme they devised improved squat strength and short distance sprint speed significantly. The improvement in sprint speed was potentially due to the increase in the hip extensors, although other muscle groups such as the knee extensors which play a vital role in the squat movement may also have experienced strength gains which may be another reason for the increase in sprint speed.

Also, the relationship between squat strength and performance has been studied many times previously. For instance, Wisloff et al. (2004) assessed if maximal squat strength could be used as a predictor of sprint speed and jump height. They found that there is a strong correlation between maximal half squat strength and speed as well as vertical jumping height. The strongest correlations were found between the 10-metre split of the full 30-metre sprint and half squat strength suggesting that improving squat strength is most beneficial for improving acceleration although there was still a significant correlation found between half squat strength and the full 30-metre sprint time. This study did, however, only test for maximal half squat strength rather than full squat strength as in our study and also tested international level soccer players meaning that the subjects might have increased strength and speed as a result of high-performance training and increased strength may not be the cause and effect of increased speed. That said, even though the previous study compared relative half squat strength and jump performance, further research in this field has incorporated full squats during a 1RM test. Relative dynamic strength appears to be the greatest predictor of vertical countermovement jump performance as there have been significant correlations found between vertical countermovement jump height and relative squat 1RM results (Nuzzo et al., 2008). This would be expected due to the similarity in knee extension movement when performing both tasks therefore greater jump performance would be expected in individuals with greater squat 1RM results.

Similarly, Comfort et al. (2014) had youth soccer players perform a predicted maximal squat test, a 20-metre timed sprint, squat jumps and countermovement jumps. They found that absolute squat strength significantly correlated with 5 metre sprint times and both vertical jumps, but relative strength showed a stronger correlation with 20-metre sprint times. Somewhat conversely, Young et al. (1995) concluded that no significant correlation could be found between starting sprint speed (first 2.5 metres) and relative or absolute strength suggesting that improving maximal strength may only be beneficial for improving speed over longer distances such as 40 metres. Young et al. (1995) did require a static, four-point stance start, as in our study, during the sprint tests although their use of junior track and field athletes as subjects could command a greater performance during the test due to familiarity of the static start.

These findings were echoed in a study by McBride et al. (2009) who looked again to examine the relationship between maximal squat and sprint times. Each participant performed a 1RM test and this was divided by the subject's body weight (relative squat strength). As expected, there was a strong correlation between relative squat strength and 40-yard sprint times where the individuals with a higher 1RM squat in comparison to their body weight were quicker over 40 yards and over a 10-yard split. The higher relative squat strength did not seem to correlate with the 5-yard split time however possibly showing that first step quickness is not associated with a higher 1RM squat.

Some researchers have found that it is power rather than strength which correlates with sprint speed (Cronin and Hansen, 2005). Strength can be described as a muscles ability to produce force whereas power includes a component of speed where it can be described as a muscles ability to produce force quickly. Cronin and Hansen (2005) found that the three measures of speed recorded were not significantly greater in individuals with greater squat 3RM, drop jump or isokinetic strength but rather with a weighted squat jump and weighted countermovement jump.

As the present study is using physically active but non-resistance trained subjects it is important to consider previous research on this population as well as in trained athletes as referenced previously. A study by Comfort et al. (2012) compared maximal squat strength and sprint times between professional rugby league players (n=24) and recreationally trained individuals (n=20). A comparison of the 5-metre sprint times between the two groups provided no significant differences although the 10-metre and 20-metre times were significantly quicker in the trained athlete group. When comparing strength, it was found that the athlete group, as expected, had higher absolute strength but no significance was found comparing the relative strength between the groups. A negative correlation was found between relative strength and 5-metre sprint times in both groups providing evidence that squat training to improve maximal strength could be beneficial when looking to improve first step quickness. Another negative correlation was found only in the recreationally trained group when comparing 10-metre and 20-metre sprint times and relative squat strength meaning that for the non-athlete population improving maximal squat strength may be of more importance when looking to improve longer distance sprint times. The finding here on recreationally trained individuals has contributed to the current hypothesis that relative squat strength may provide the greatest correlation with 40-yard dash time. The relationship between relative squat strength and sprint speed as well as apparent lack of relationship between absolute squat strength and sprint speed is why the present study will convert 1RM to 1RM/BW.

These correlations between squat strength and performance measures can form hypotheses that squat training would result in improved performance measures. Seitz et al. (2014) used a meta-analysis to find out if this was the case. They found that due to large effect sizes in squat strength and sprint performance it could be suggested that improving lower body strength through a lower body training programme may result in improved sprint performance. This knowledge can be used by coaches to form programmes aimed at improving lower body strength in order to improve performance measures and ultimately improve sporting performance.

Although the squat is highlighted as a quality compound movement when looking to improve performance measures through improvement of strength in various muscle groups, it is a highly technical movement and carries risks of injury in non-resistance trained individuals (Kravitz et al., 2003). Other lifts incorporating use of the same muscle groups, such as the hip extensors, may be more suited to non-resistance trained individuals. The hip thrust may therefore be a more accurate tool in assessing the strength of the hip extensors and provide a truer representation of hip extensor strength in non-resistance trained individuals.

Previous research on hip thrust

The less technical nature of the hip thrust could be beneficial to individuals being introduced to weightlifting due to the ability to lift higher weight volume per session. The ability to progress to higher training volumes quicker may result in quicker performance adaptations due to the potential strengthening of the muscles used.

Contreras et al. (2017) compared the potential performance benefits of the hip thrust and the front squat and found that both lifts were potentially beneficial for different reasons. It was concluded that improvements were shown in 3-repetition maximum (3RM) performance in the movement performed by each group. However, the squat group improved most in the vertical jump, whereas, the hip thrust group improved 10-metre and 20-metre sprint times to a greater degree. This is potentially due to the hip thrust training enhancing horizontal force production through a greater increase in strength of the hip extensors which could be transferred to sprint running. Not in accordance with what was previously hypothesised however, the hip thrust did not have a significant effect on horizontal jumping performance.

Although this study was conducted to determine the potentially beneficial performance effects of a weight lifting training intervention and not the initial strength, the fact that an increase in strength over the course of the study and the corresponding increase in performance could suggest that hip thrust strength and front squat strength are important for performance measures. Again, this study used adolescent males (n=20) as a subject group meaning that they will be more accustomed to resistance training and will potentially have already experienced performance benefits previously. However, the fact that the subjects are between the ages of fifteen and eighteen years old suggests that not all will have had extensive resistance training and might be closer in training level to our subjects than adult athletes in other studies cited.

Recently however, Bishop et al. (2017) found that after an 8-week hip thrust training study, the subjects showed significantly improved hip thrust 1RM strength but not improved 40-metre sprint times. Similarly, another 8-week training intervention found that hip thrust training increased hip thrust 3RM strength but the increased strength in the movement did not lead to an increase in the performance measures tested (vertical jump, broad jump and 30 metre sprint time) (Lin et al., 2017). Both these recent studies are partly in conflict with the previous study mentioned (Contreras et al., 2017) where it was found that hip thrust strength produced an increase in sprint times over 10 metres and 20 metres. The studies by Lin et al. (2017) and Bishop et al. (2017) did not, however, record sprint times at the 10-metre and 20-metre splits during the 30-metre or 40-metre sprints. This point is potentially important because it is theorised that hip thrust strength could increase acceleration, therefore not measuring the split times would miss potential improvements. A potential flaw in the training intervention used in the Bishop et al. (2017) study is the possible lack in weight progression each week throughout the programme. Subjects only increased the weight by 2.5% if they were able to exceed 5 reps in the last set of their hip thrust training. Due to already performing 4 sets of 5 reps previous this, fatigue may have been a factor in not achieving the goal required to increase weight.

Also, in the training intervention devised by Lin et al. (2017) subjects performed a high number of reps at low weight before progressing late in the hip thrust programme which may have limited strength gains expected after performing the hip thrust at heavier loads and less reps (Anderson and Kearney, 1982).

Studies by Bishop et al. (2017) and Lin et al. (2017) could also have identified correlations between strength and performance measures both pre and post intervention in order to gain a clearer idea of whether hip thrust strength gains could be a cause of increased sprint performance.

Overall, it is unclear if in an increase in hip thrust strength and simultaneous increase in strength of the muscles used during the movement are responsible for improvements in performance measures. Some previous studies have found significant improvements in performance measures through a hip thrust training intervention whilst others have not. Due to knowledge of hip extensor strength and the possible implications on performance measures, we hypothesise that there is a relationship between hip thrust strength and performance outcomes.

Another popular compound movement used in training programmes is the deadlift. It is technical in nature like the squat but may be beneficial in performance enhancement through an increase in strength of the knee flexor muscles.

Previous research on deadlift

As mentioned, previous research on deadlift strength and the correlations with performance are limited. The main muscle group used during the movement is the knee flexor muscles making it a key movement in many training programmes due to the relationship between knee flexors and performance measures. This relationship suggests the potential for increased performance through deadlift training.

The hamstrings are thought to be critical for sprinting compared to the quadriceps which are thought to be used to a lesser degree (Schache et al., 2012). With that in mind, it would make sense to assume that individuals with stronger hamstring muscles, such as the biceps femoris, will be able to produce greater maximal speed during a sprint. The activation of leg muscles during a deadlift was examined by Wright et al. (1999). They found that the hamstring muscles were activated approximately 50% more during a deadlift than during a squat suggesting that deadlift strength may help with sprint performance.

Similarly, when comparing the activation of hamstring muscles during a deadlift versus a hip thrust Andersen et al. (2017) found that the greatest hamstring muscle activation was during the barbell deadlift whilst the hip thrust provided the greatest activation in the gluteus maximus. This could suggest that an increase in hip thrust strength may result in an increase in hip extensor strength while an increase in deadlift strength may result in an increase in knee flexor strength.

Study aims and hypotheses

The aim of this study is to evaluate if any correlations can be identified between relative one rep max (1RM) strength across three different compound movements and performance measures such as sprint performance, jumping performance and performance in a change of direction test. The three movements undertaken by participants were the back squat, deadlift and hip thrust. Although many previous studies have observed the link between squat strength and performance measures, little is known about hip thrust or deadlift strength as predictors of performance. This study will also be examining the link between performance in each of the performance tests to identify if any correlations are present.

The author hypothesises, through previous research, that individuals with greater hip thrust strength will produce better results in 10-yard sprint time and broad jump distance due to the similarities of movement along a horizontal plane during sprint acceleration and horizontal jumping which is comparable to the hip thrust movement. It is also hypothesised that greater back squat strength will negatively correlate with 40-yard sprint time and positively correlate with vertical jump height through the use of both hip extensors and knee extensors during a squat movement which is deemed vital to sprint and vertical jump performance respectively.

Strength in the hip extensor muscles are thought to be pivotal in the squat movement as well as during performance tasks such as sprinting and jumping. Speculation can therefore be made that improving strength in the hip extensor muscles through training involving compound movements could result in improved performance measures through tests and ultimately in performance during sporting competition. Also, the fact that an untrained population is used in the present study will provide further knowledge on whether the hip thrust is an optimal compound movement for beginners to weightlifting due to its less technical nature compared to the squat and deadlift movements.

Methods

This correlational study is part of a larger training intervention study involving subjects being split into groups and training the three compound movements examined in this study for 6 weeks. The data from the baseline measures taken such as one rep max (1RM) and all performance tests are used in this study to form correlational data on hip thrust, squat and deadlift maximal strength and performance measures as well as correlations between results in each of the performance tests.

Subjects

This study consisted of 31 male voluntary participants recruited by all members of the training intervention study. Only males were selected for the study in order to keep the results consistent. Inclusion criteria included participants who were recreationally active (exercised for approximately 3 hours per week), but non-resistance trained (had not lifted weights in the last 6 months) and were not suffering from any injuries prior to the beginning of the study. A PAR-Q (Physical Activity Readiness Questionnaire) was completed prior to initial testing excluding any participants who were at risk of injury or complications through injury or who may produce adverse results for any reason such as medication or previous injury. Ethical approval was given by the University of Stirling ethics committee prior to the study commencing.

Procedure

The training intervention study took place over a 9-week cycle with a familiarisation week (week 1), pre-intervention testing week (week 2) (Figure 3), a six-week training intervention performing one of the three movements and a post-intervention testing week (week 9). The current study is using results taken from the initial testing period (week 2) and observes correlations at baseline.

The testing week required the subjects to attend the lab on three separate occasions to perform several tests (Figure 3). Day one included ultrasound of the gluteus maximus, biceps femoris, vastus lateralis and rectus femoris; tensiomyography (TMG) of the same muscles; isometric testing including maximum voluntary contractions (MVC) during knee extension and flexion and hip extension followed finally by isometric push and pull tests. Data from these tests would not be used in the present study although data was collected by myself and other researchers.

The morning following this battery of tests subjects would arrive again to complete performance tests which would produce data used in our study.

Finally, two days after the performance tests, the participants would complete a 1RM test in the back squat, hip thrust and deadlift also providing data used in our study.

All performance data was collected by myself as well as a large section of the 1RM data.

Figure 3 – Testing timeline

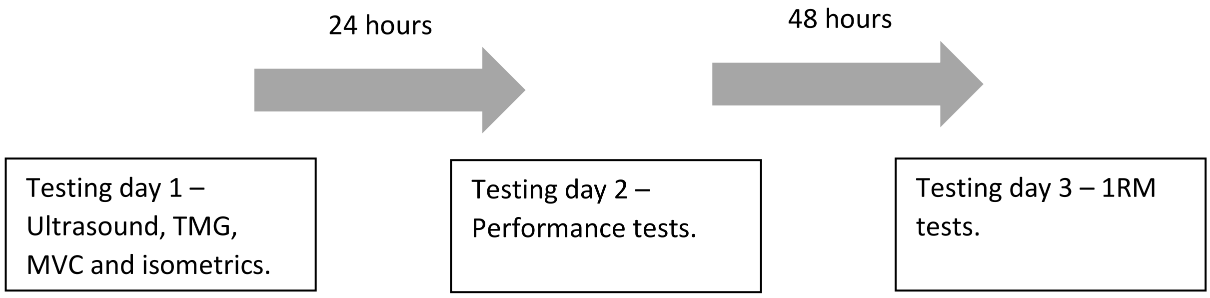

Figure 3: Schematic showing the testing procedure for each day of testing and the time elapsed between, as explained in full detail previously (Weeks 1,2 and 9).

Performance testing procedure

Each subject completed five performance tests on the one day. The tests were 40-yard dash, pro agility test (5-10-5 change of direction test), medicine ball rotational scoop toss, countermovement jump and standing broad jump, in that order. Subjects performed an approximate 5-minute self-selected warm-up through light jogging and dynamic stretching of the lower body. The 40-yard dash, pro agility test and medicine ball scoop toss were performed on an indoor tennis court surface whilst the two jump tests were performed on a force platform with the broad jump landing area being standard indoor vinyl flooring. In all tests, the subject's best times and distances were used for later analysis as using the mean of all three may significantly lower a subject's results through the possibility of an uncharacteristically bad test.

Sprint speed test

The 40-yard dash was performed by each subject one after the other using the walk back from the end of the track as the recovery period between sprints which would be performed three times by each participant. The times were captured by infrared motion sensors (Brower Timing Systems, Draper, Utah, USA) positioned at the start line, 10 yards from the start line, 20 yards from the start line and 40 yards from the start line. The subjects were instructed to position themselves in a four-point stance with their hands touching but not covering the start line before sprinting. The time commenced as soon as movement was detected by the initial camera through the initiation of the sprint and produced three readings including 0-10 yards, 0-20 yards and 0-40 yards (Nesser et al., 1996).

5-10-5 change of direction test

The pro agility test was completed three times by each subject also with the same rotational system as the 40-yard sprint. Subjects would stand either on the left or right-hand side of a solid white line where one infrared motion sensor (Brower Timing Systems, Draper, Utah, USA) was positioned, this would be their start and finish line and would also provide a split time mid-test. The pro agility test procedure can be seen in figure 4.

Figure 4 – 5-10-5 Change of Direction Test

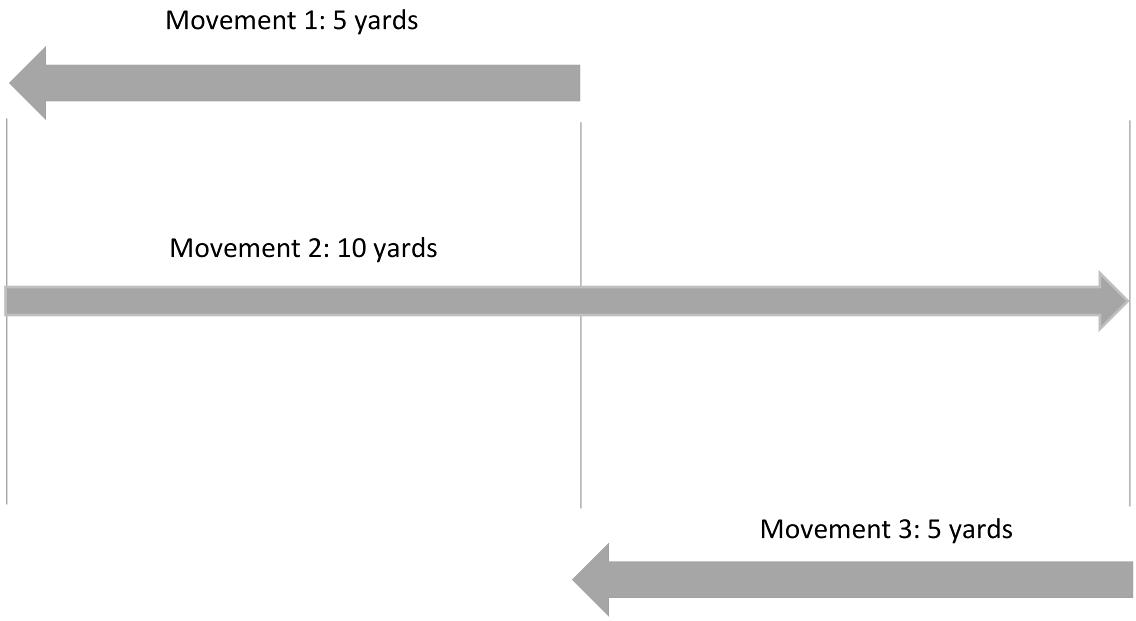

Figure 4: Diagram showing the movement during the 5-10-5 change of direction test. In this example, the participant begins at the centre line (solid white line) before sprinting 5 yards to the left turning at the left line (cone) and turning completely to sprint 10 yards to the right line (cone) and finally turning completely again to sprint 5 yards through the centre line where the test is completed (Sayers et al., 2015).

Medicine ball rotational scoop toss

The medicine ball rotational scoop toss measures how far the subject can throw a medicine ball using a rotational scooping motion. A measuring tape was extended from a starting line to measure how far the ball had travelled. Each subject would elect to either throw the ball to their right or left with their corresponding foot positioned touching the line. The ball would be thrown leaving a distinctive mark on the ground and a straight edged dowel was then used to identify how far along the measuring tape the ball had travelled. A 4-kilogram ball was used by each subject (Ikeda et al., 2006).

Vertical jump test (Countermovement)

The vertical jump test was performed on a force plate (K Toyo 266A load buttons/500Kgf) with a straight wooden dowel held across the shoulders attached to a transducer (Celesco, Chatsworth, California, USA) which recorded a trace via AcqKnowledge software (Biopac, Goleta, California, USA) on a laptop linked to a corresponding Biopac unit, used to measure the height of each jump. Each subject performed three countermovement jumps to warm up and become familiar with the landing area before the recorded jumps where the participant had to squat down before jumping as high as possible with no pause at the bottom of the squat. The three jumps were performed one after the other with as much of a break between each jump as the subject desired (Harman et al., 1991) .

Standing broad jump

The broad jump was again performed on a force plate (K Toyo 266A load buttons/500Kgf) where the subject would position their toes at the front edge of the force plate and jump as far horizontally as possible landing in a stable position next to a measuring tape. Subjects also had performed three practice attempts before this test for the same reasons as the vertical jump. The distance of each recorded jump was then measured by placing a straight wooden dowel behind the heels and across the tape measure to give the distance jumped. Each of the three jumps were performed with approximately a minute long rest between (Castro-Pinero et al., 2010).

1RM Testing

The 1RM data was collected on week 2 of the 9-week phase where a familiarisation session was completed the previous week. The familiarisation session gave the subjects a chance to be coached on how to perform the three lifts correctly and safely and also gave the research team an idea of where the 1RM range would be.

The familiarisation week 1RM session involved coaching the subjects on correct form for the back squat, hip thrust and deadlift sequentially. A rate of perceived exertion (RPE) scale was used after the first lifting attempt at 10 reps in order to determine how much weight to add each progression, going to 5 reps, 5 reps, 3 reps, 2 reps and finally 1 rep until a 1RM could be deduced. The increasing increments in weight were assessed by the researchers adding 10kg if the RPE was 8 or below and adding 5kg if the RPE was 9 or above. The weight would be reduced slightly if the subject failed an attempted lift, but the researcher felt they could make another attempt at a lighter weight.

The lift was called as a fail if the subject could not physically lift the weight attempted or the form was not correctly adhered to. On the back squat the lift was called a fail if the subject did not or could not squat to parallel, the hip thrust was called a fail if the subject did not lift the barbell to a horizontal body position and the deadlift was called a fail if the lower back started to round excessively. All three lifts were watched intently by a researcher determining if the correct form was achieved and the lift could be counted. If the lift was failed, then the subject would have a further two opportunities to complete the lift at that weight and after three failed attempts the last completed lift would be recorded as the unofficial 1RM. The following week the subjects would complete a similar protocol in order to find the official 1RM.

To warm up and build up to the 1RM attempts the subject first did 10 reps with an unloaded 20kg barbell for the back squat and with a 20kg barbell loaded with two 5kg training plates for the hip thrust and deadlift. The subjects would then perform 5 reps at 50% unofficial 1RM followed by 5 reps at 70% unofficial 1RM, 3 reps at 85% and 2 reps at 90%. The RPE scale would then be used again when approaching the 1RM attempts and if the subject reported an RPE of 8 or below in the set of two then 100% of the previous weeks 1RM would be attempted but only 95% would be attempted if an RPE of 9 or above was reported. The subject would then attempt one rep on each weight moving up in increments of 5% unofficial 1RM if they reported an RPE of 9 or above or they would move up in increments of 10% unofficial 1RM if an RPE of 8 or below was reported. This would continue until failure on each lift where the last previous completed attempt was recorded as the official 1RM (Clark et al., 2016).

Analysis of vertical jump data

The vertical jump heights were calculated through analysis of the transducer trace on AcqKnowledge software (Biopac, Goleta, California. USA). The mean of the standing height section of the trace was subtracted from the minimum of the jump trace (maximum height of the jump) giving the difference between which was the height of the jump.

Statistical analysis

Statistical analysis of the data collected was analysed using the SPSS statistical software programme. A Pearson's correlational analysis was conducted with all the collected variables except 5-10-5 split time which is the time from start to the midway point of the test as this was not deemed a vital result.

Due to the large number of tests being carried out by the software a Bonferroni correction calculation was used to try and control the false discovery rate. Using the calculation $\alpha=0.05/n=45$, no correlations would be accepted as significant unless the p-value fell below .0011. Data for all Pearson's correlation tests run can be found in Appendix A.

Table 1 – Subject Characteristics

	Age (Years)	Height (m)	Weight (kg)	BMI (kg/m^2)
Mean	23.21	1.81	80.60	24.75
Standard Deviation	4.45	0.07	11.63	3.58

Table 1: Table of means and standard deviations for participant characteristics.

Results

31 Participants were involved in the study with 26 completing the full battery of tests. The 5 participants without a complete data set could not complete all tests due to illness/injury or personal reasons. Their results from other sections of the study could be used for other research papers.

Weight lifted in each movement

Subjects lifted, on average, more weight during the hip thrust compared to the squat and deadlift in both relative and absolute terms (Figure 5).

Correlations observed for sprint and change of direction times

All measures of sprint speed during the 40-yard dash test correlated within the test. The 40-yard dash time correlated with the 10-yard split time (ρ=.822, p=<.001) and 20-yard split time (ρ=.938, p=<.001) while the 10-yard split and 20-yard split also correlated with each other (ρ=.912, p=<.001).

All measures of sprint speed also showed correlations within the 5-10-5 change of direction test. Correlations were significant between the 40-yard dash and 5-10-5 time (ρ=.726, p=<.001); between 10-yard split and 5-10-5 time (ρ=.668, p=<.001); and between 20-yard split and 5-10-5 time (ρ=.769, p=<.001).

Finally, significant correlations were observed between all sprint speed measures and hip thrust strength. Only 40-yard dash time, but neither of the two splits, correlated with relative back squat strength (ρ=-.576, p=.001) (Figure 6). Correlations exist between 40-yard dash time and relative hip thrust strength (ρ=-.679, p=<.001) (Figure 4); between 10-yard split time and relative hip thrust strength (ρ=-.582, p=.001); and between 20-yard split time and relative hip thrust strength (ρ=-.636, p=<.001). There were no significant correlations found between relative deadlift strength and 40-yard dash time (ρ=-.441, p=.019) (Figure 6).

Correlations observed for standing broad jump distance

The only significant correlation found for broad jump distance was between relative hip thrust strength (ρ=.610, p=.001) (Figure 6).

Correlations observed for medicine ball scoop toss distance

The only significant correlation found for the medicine ball scoop toss test was between the distance and the 5-10-5 test time (ρ=-.600, p=.001) (Figure 6).

Correlations observed for relative strength

Back squat relative strength showed significant correlations with deadlift relative strength (ρ=.573, p=.001).

Correlations observed for vertical jump height

The vertical jump test produced no significant correlations for jump height.

All correlations including the ones not included in the graphs can be found in Appendix A.

Figure 5 – Means and individual values in 1RM and performance tests

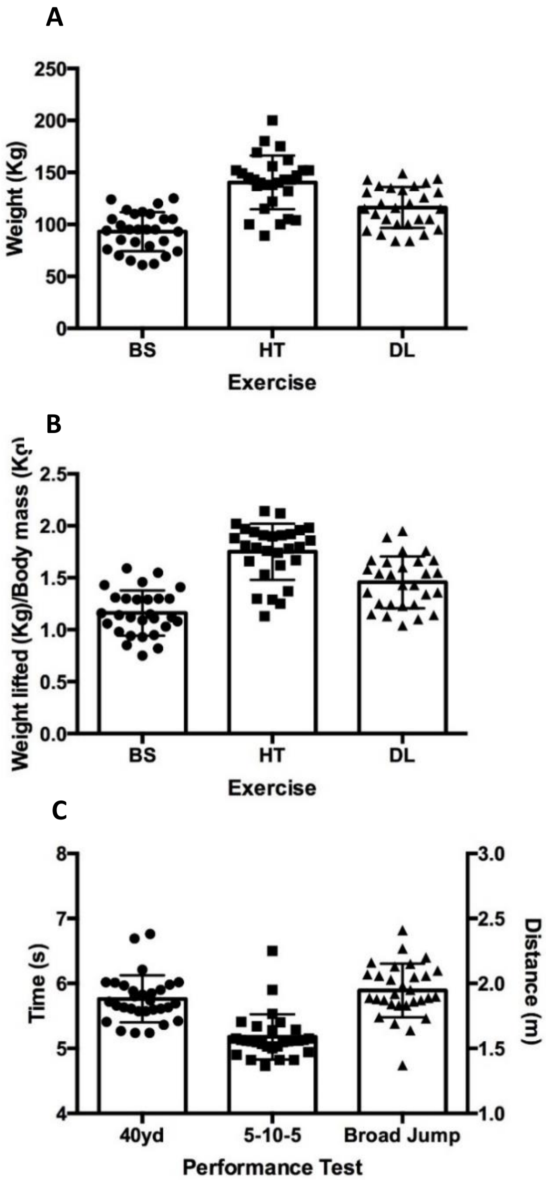

Figure 5: Bar chart of means, plus or minus standard deviations, with individual values overlaid. (A) absolute 1RM in each movement (raw weight lifted); (B) relative 1RM in each movement (1RM/body mass); (C) times recorded in the 40-yard dash and change of direction test with broad jump distance on the alternative y-axis.

Figure 6 – Correlational data

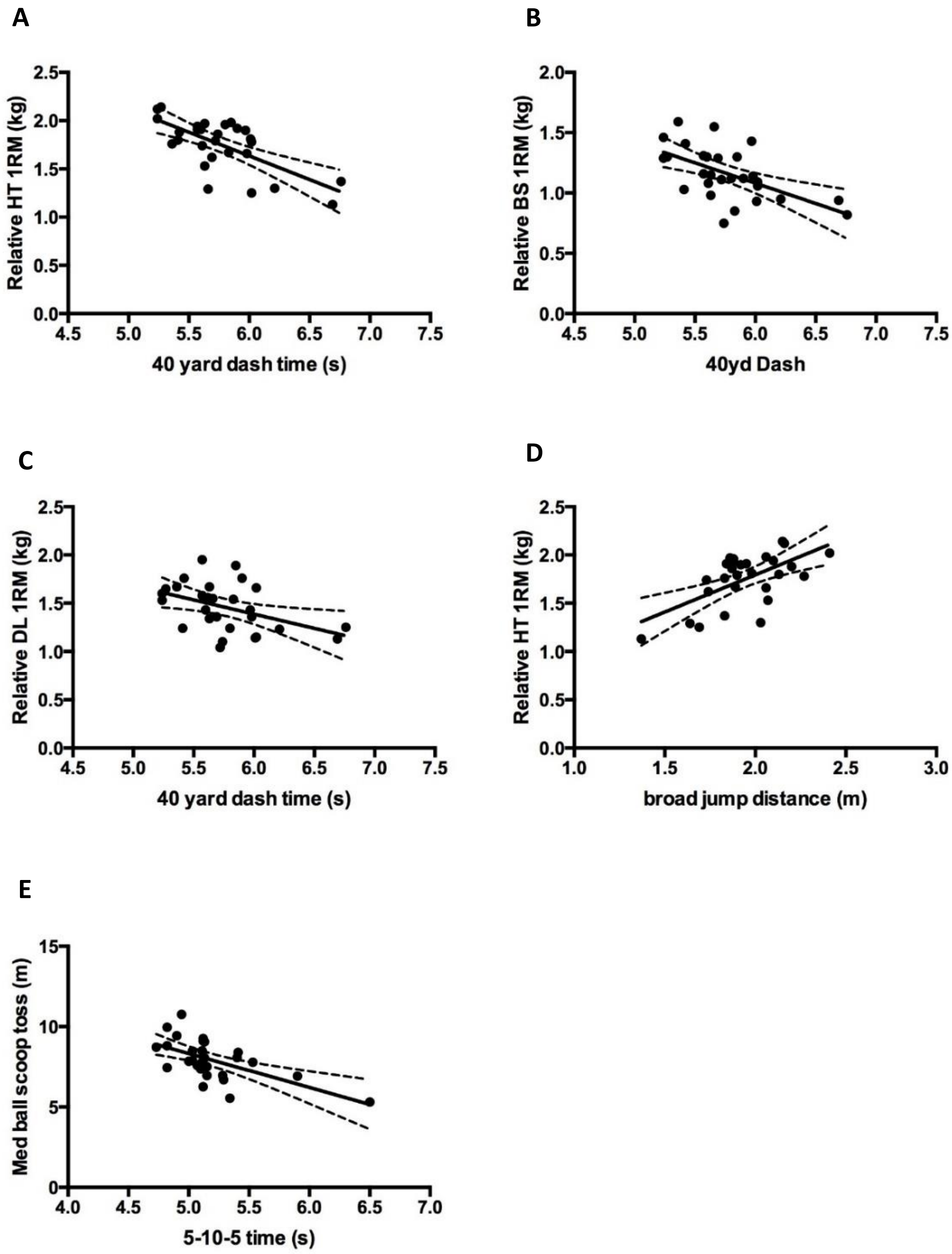

Figure 6: X Y Scatter plots with fit lines, plus or minus 95% confidence, showing correlations between variables on axes. All variables that were compared through a Pearson's correlation were only accepted as significant if the p-value was below 0.0011 through a Bonferroni correction calculation. (A) significant negative correlation between 40-yard dash time and relative HT 1RM. (B) significant negative correlation between 40-yard dash time and relative BS 1RM. (C) non-significant negative correlation between 40-yard dash time and relative DL 1RM. (D) significant positive correlation between broad jump distance and relative HT 1RM. (E) significant negative correlation between 5-10-5 time and medicine ball scoop toss.

Discussion

The primary aim of this study is to determine if a relationship exists between performance measures, such as sprinting and jumping, and strength in three different compound movements. In relation to the primary aim, our results suggested that greater strength in the back squat and hip thrust movement correlate with greater sprint performance. Our results also suggest a correlation between greater hip thrust strength and sprint performance over 10 yards as well as broad jump distance. There were no correlations found between vertical jump and any other variables although there was a correlation found between increased medicine ball scoop toss performance and change of direction performance.

Firstly, all measures of sprint speed correlate with each other meaning that the 40-yard dash time correlates with the 10-yard and 20-yard splits collected during the test. The finding seems obvious as you would expect the faster a participant ran over 10 or 20 yards, the faster they would run over the full 40 yards. Nesser et al. (1996) found a similar correlation when comparing the speed over 5 and 10 yards to a full 40-yard dash suggesting that greater first step quickness and rapid acceleration were pivotal to a quicker 40-yard dash time. The fact the present study used 10 and 20-yard splits and found significant correlations also could indicate that the maintenance of speed is equally vital to running faster over a longer distance such as 40 yards. Our first findings on correlations between strength and performance measures are the negative correlations between squat strength and 40-yard dash time and the negative correlations found between hip thrust strength and 40-yard dash time, as well as the split times (10-yard and 20-yard). The relationship between squat strength and sprint performance has been largely documented previously with Wisloff et al. (2004), McBride et al. (2009), Comfort et al. (2012). Collectively, these data support the present findings that greater squat strength correlates with better sprint performance. The strength of correlations are higher in the paper by Wisloff et al. (2004) between squat strength and 30 metre sprint time ($_{\rho}$ =-.94) compared to the correlations found between squat strength and 40-yard dash time in our study (ρ =-.576). This could be due to the difference in distance used during the sprint test or the fact that international level soccer players were used during the Wisloff et al. (2004) study and strength and sprinting ability is expected to be higher.

Somewhat conversely, correlational results on the relationship between squat strength and 40-yard dash times obtained by McBride et al. (2009) (ρ=-.6048) were similar to results in our study (ρ =-.576). They did however find a significant correlation between squat strength and 10-yard sprint times whereas our results between those tests are not significant. Like the Wisloff et al. (2004) study, McBride et al. (2009) used professional football players as the subject base but did use the same 40-yard dash test as in our study.

In terms of previous correlations found between squat strength and sprint performance in recreationally trained subjects, Comfort et al. (2012) found significant correlations over 10-metres and 20-metres (ρ =-.621) and (ρ =-.604) respectively. Although the correlations between squat strength and sprint performance found in our study are over 40-yards, the strength of correlations are again similar to another study.

The relationship between the two variables could be indicative of the strength of the knee extensors, such as the vastus lateralis and rectus femoris, and their importance in both sprinting and the back squat. Previous research on the EMG activation during the squat has been studied by Isear et al. (1997), Robertson et al. (2008), and to an extent Camara et al. (2016), due to the suggested similarities between the hexagonal bar deadlift and back squat by Andersen et al. (2017). All studies found that the knee extensors are activated to a greater extent than the knee flexors during a squat.

Similarly, Newman et al. (2004), suggested a relationship between knee extensor and flexor torque and sprint speed. The strongest relationship however was found between peak knee extensor torque and the initial 10-metre section of the sprint, which could be the reason greater squat strength and therefore potentially greater knee extensor strength and power associates with the sprint tests. Our data however on the relationship between relative squat strength and both split times (10-yard and

20-yard) suggest that squat strength does not correlate with acceleration over 10 yards or speed maintenance over 20 yards. Our data therefore indicate that, in a non-resistance trained population, a factor other than knee extensor strength may be responsible for acceleration. This assertion is supported by Kin-Isler et al. (2008), having previously found no relationship between knee extensor strength and sprint speed in a study within a non-athlete population and a similar subject number (n=28).

The negative correlation between relative hip thrust strength and sprint speed across all measures reflects our hypothesis. Contreras et al. (2017), found similar results when comparing the hip thrust and front squat where more improvements were found in the hip thrust training group compared to the front squat group in the 10- and 20- metre sprint times. It should be noted, however, that although the front squat and back squat are similar exercises, a direct comparison cannot be made between the two and only an assumption of similar outcomes can be made. The correlation between both split times and relative hip thrust strength is perhaps connotative of the type of movement required during acceleration which Contreras et al. (2017) previously hypothesised along a horizontal force vector. It could be deduced that the horizontal movement required to begin a sprint from a static position through acceleration is similar to the movement required to hip thrust effectively and that greater strength in the movement will produce greater sprint acceleration.

Also, our results suggest that a stronger correlation exists between hip thrust strength and speed compared to back squat strength and speed. The stronger correlation between relative hip thrust strength and full 40-yard dash time suggests that this improved acceleration and maintenance of speed over 10 and 20 yards respectively affects the overall sprint speed time. This may be due to those individuals with a stronger hip thrust accelerating quicker as indicated by the correlations between relative hip thrust strength and the 10-yard and 20-yard splits.

The present findings do however conflict with the findings of Lin et al. (2017) and Bishop et al. (2017), who suggested that the increased hip thrust strength caused by a training intervention does not significantly improve performance, including sprint speed measures. There was, however, no direct comparison between the hip thrust strength and performance measures before or after the intervention which may have shown results comparable to this study. This may be an indication that strength in the hip thrust movement correlates with increased sprint performance although improving hip thrust strength through training may not translate to improved sprint performance as a result of the hip thrust training.

It appears that the hip extensors such as the gluteus maximus may also play a vital role in sprint running. Andersen et al. (2017), as previously mentioned, found the gluteus maximus, a large muscle making up part of the hip extensors is activated to the greatest extent during a hip thrust compared to a straight bar and hexagonal bar deadlift. Whilst the knee flexors are still activated more than the knee extensors during a hip thrust movement, the hip extensors are likely the main force generators during the hip thrust (Contreras et al., 2015). Hip extensor and flexor strength also appear to have a strong relationship with sprint performance, so it may be that the strength required by both these muscles in the hip thrust movement translate to the muscles required for sprint performance. There was however no studied relationship between sprint speed and knee extensor and flexor strength making it difficult to conclude which muscle groups are working synergistically.

That being said, it could also be suggested that the hip flexor muscles act together with the knee flexors, even more so than the muscles positioned around the knee do during sprint running (Chumanov et al., 2007). The knee flexors also seem to have a major role during sprinting, meaning that potentially greater knee flexor strength may result in faster sprint performance. It is very hard to say from the data collected in this study however if the knee flexors are playing a role in performance in any of the tests conducted. Conclusions of Chumanov et al. (2007), as well as those of Schache et al. (2012), explain the use of the hamstrings during sprinting where the peak force of the biceps femoris muscle increased as sprint speed increased outlining the large role played by the knee flexors during sprinting. With this in mind, it makes it unusual to find that relative deadlift strength looks to have no significant correlation to sprint speed across any of the three variables due to the large activation of the hamstring muscles during the deadlift exercise. Findings of Wright et al. (1999), Isear et al. (1997), Camara et al. (2016), and Andersen et al. (2017), show that the greatest hamstring activation occurs during the deadlift when compared to the other two movements performed in this study. All of these studies except the Isear et al. (1997) study used trained subjects although this is not expected to affect results of an EMG analysis. The Isear et al. (1997) study also had a large number of untrained subjects tested (n=41) and found that hamstring activation is greater during the deadlift as with the studies on a trained population. The lack of relationship found between deadlift strength and sprint performance is perhaps due to the lack of activation of the hip extensors compared to the hip thrust movement. The large activation of the hip extensors coupled with the fact there is still knee flexor activation during the movement (Andersen et al., 2017) mean it could be deduced that the hip thrust is a superior movement when looking to improve acceleration and overall sprint speed due to the work of both muscle groups during sprinting.

Further to this, previous findings by Robertson et al. (2008) relate to our current findings due to the knowledge that hip extensors also play a part in the squat movement. Due to the activation of the gluteus maximus during the initial phase of the ascent, it could be expected that greater squat strength will correlate with greater hip extensor strength, as would also be expected with greater hip thrust strength. The correlation between squat strength and 40-yard sprint speed backs up the previous thinking that hip extensor strength has a large influence on sprint performance.

Also, something worth noting in this study is the part played in the squat movement by the ankle plantar flexors and again the assumption that stronger ankle plantar flexors result in greater squat strength. This can be linked to earlier work where it was suggested that stronger ankle plantar flexors resulted in a slower 40-metre sprint time (Nesser et al., 1996). The negative relationship between squat strength and 40-yard sprint time could indicate the opposite about ankle plantar flexors although it is impossible to say due to the other, larger, muscle groups working during sprinting which could suppress the need for greater ankle plantar strength.

The relative strengths across the three lifts cannot however be viewed as the cause and effect of greater sprint speed no matter how strong the negative correlation appears to be, or how weak the correlation is in the case of relative deadlift strength. The fact that running style varies between individuals may cause a difference in sprint times due to stride length and number of steps throughout the test rather than because of the strength of the muscles used. Hewit et al. (2013) found that many factors, including those mentioned previously, and knee lift and forward lean all contributed to differences in times over a straight sprint and in change of direction tasks such as the 5-10-5 test used in our study. However, the single straight sprint test was only over 2.5 metres which may not be applicable to the full 40-yard dash test used in our study. This is similar to the findings of Kunz and Kaufmann (1981) which also attributed angles at which the thighs are positioned throughout the sprinter's running technique to their overall sprinting performance. As we did not account for differences in running style and technique, it is unknown if this made a significant difference to the results found.

Another outcome of the present study is the strong correlation between relative hip thrust strength and broad jump distance. As hypothesised, subjects with a greater relative hip thrust strength could jump further in a horizontal direction when compared with strength in the back squat and deadlift. This is in line with the theory, mentioned before, about sprint acceleration that Contreras et al. (2017) proposed about a horizontal force vector and the ability to move weight along this vector is similar to the movement of a horizontal broad jump. Although, the results of the Contreras et al. (2017) study did not confirm this. The fact that the results of this study show a strong correlation between the two variables could suggest that the two are indeed linked through movement along a horizontal force vector and strength coaches may look to employ this exercise in a programme to improve sprint and jump performance. Similar to the suggestion of muscles used during acceleration whilst sprinting, the broad jump technique may rely on the hip extensors and promote the idea that an increase in hip extensor strength through training involving the hip thrust possibly improves broad jump performance.

A somewhat unexpected finding is the lack of correlation between vertical jump and any of the other measures collected. It was previously hypothesised that vertical jump height would correlate with relative squat strength due to the similarities in muscle recruitment during both activities, whereas stronger muscles and more ability to produce force would result in a higher vertical jump. Many previous studies (Wisloff et al., 2004); (Maulder et al., 2008); (Comfort et al., 2014) have suggested links between vertical jump performance and performance in other activities such as sprint running and 1RM tests. We expected that vertical jump performance would correlate with sprint speed in at least one of the sprint speed measures due to research by Maulder et al. (2008), and Smirniotou et al. (2008). The lack of relationship between vertical jump height and sprint speed agrees with Meylan et al. (2009), in that they concluded no jump tests were good predictors of sprint speed. There was also no significant correlation observed, in our study, between broad jump distance and sprint speed measures further emphasising this idea. This could perhaps be due to the design of our study as a conventional bilateral countermovement jump was performed. It has been shown previously that unilateral vertical jumps are better predictors of sprint speed when compared to bilateral jumps (McCurdy et al., 2010). The lack of correlation between vertical jump and sprint speed in the present study could be attributed to the choice of test.

Also, a further finding, which was not hypothesised but is worth noting, is the relationship between medicine ball rotational scoop toss and time in the 5-10-5 change of direction test. The significant negative correlation between tests suggest that the medicine ball scoop toss may be an effective tool for predicting change of direction performance and that emphasising training on the muscles dominating both movements could improve change of direction performance. It is not quite clear in which way the two tests may possibly interact through movement patterns or strength of a particular muscle group, which may be an interesting subject of a later study. Although, Ikeda et al. (2006) found that the side medicine ball throw test may be a useful tool for predicting rotational power of the trunk. Therefore, we postulate the relationship between the medicine ball scoop toss and change of direction test is through the rotational movement in both tests and that the ability to do so efficiently gives rise to the correlations found.

Another observation, that is not related to correlations between tests, is the mean relative weight lifted across the three movements where it is clear it is possible to lift greater weight in the hip thrust during a 1RM test compared to back squat and deadlift. As shown previously in figure 3, both the relative and absolute weights lifted by individuals is greater than deadlift and even greater again than back squat. This observation suggests that the hip thrust may be a superior exercise for beginners to weightlifting. The greater weight lifted in the hip thrust by untrained individuals in this study could imply the subjects find the hip thrust easier to execute with less technical ability. Previous suggestions about 1RM tests, particularly in untrained individuals, are that lifting the maximal weight possible could be dangerous and lead to injury (Mayhew et al., 1995); (Kravitz et al., 2003); (Rontu et al., 2010). The fact that subjects could lift, on average, approximately 1.75x their own bodyweight during their first attempt at an official 1RM suggests this exercise could be used as an introduction to weightlifting and weightlifting assessments compared to the more complex squat and deadlift techniques. The hip thrust therefore could be a useful tool to enhance hip extensor strength in beginners whilst they are learning more technical lifts.

<u>Future Research</u>

A further study which is underway and can further examine the results found in this study is a training intervention directly comparing the back squat, hip thrust and deadlift in an untrained population. It is important to determine whether the fact that relative strength in each movement before any training and the correlations produced are transferrable to a training intervention study and the post-intervention observations.

Another potential study, derived from our study, would be to replicate the training intervention study on a resistance trained population and look at the potentially different results as well as providing more reliable data to be used by a trained population and strength coaches. The present study is important to provide normative data to be compared to and has provided evidence that the hip thrust is an ideal movement for beginners to weight lifting. Recently, a pilot study by Zweifel et al. (2017) was run to test the feasibility of the full study comparing the effects of squat, hip thrust or deadlift training on performance measures such as sprint speed, change in direction and jump performance in a trained population. Although this was just a pilot study it is worth noting that large effects sizes (r=>0.5) were found for the hip thrust vs control on broad jumps and 40-yard sprint time. The only potential limitation with the training intervention study on trained individuals is the reduction in overall weightlifting and potential limitation of strength losses rather than actual strength gains and performance enhancements due to the addition of weightlifting in an untrained population.

Further to this, a future study could use female subjects as opposed to solely male subjects as in our study. This would provide more data on the correlations between strength in certain movements and performance measures and further to this a training study would suggest potential adaptations as a result of strength training in females. The data could also be compared between studies and highlight differences between results in males and females. The fact that previously, Contreras et al. (2015) studied the EMG activity of various limb muscles during different movements such as the hip thrust shows there is scope for increased knowledge on resistance training in females.

Conclusion

In conclusion, these results suggest that there are correlations between strength in both the back squat and hip thrust and performance measures. Previous research by Contreras et al. (2017) on hip thrust training interventions and the hypotheses derived from these have been backed up by the findings in our study. Our findings also conform to the findings on back squat strength by Wisloff et al. (2004), Comfort et al. (2012) and Comfort et al. (2014) as well as findings by Seitz et al. (2014) on lower body training and sprint performance. This has given insight into the muscle groups important for performance providing possible training programmes to follow when looking to improve overall sporting performance.

It could be suggested, through the current findings, that strength coaches may provide individuals with a strength training programme involving both the back squat and the hip thrust due to possible enhancement of performance. It may be most beneficial to improve hip extensor strength through these two compound movements for an individual looking to potentially improve performance measures and subsequently improve sporting performance. Furthermore, hip extensor strength may be examined more efficiently and accurately using a hip thrust 1RM test as opposed to a back squat or deadlift 1RM test in non-resistance trained individuals. The less technical nature of the hip thrust may provide a truer representation of hip extensor strength in individuals who are not used to performing technical movements like the squat.

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Appendix A

Correlations

		40 yard dash time (s)	10 yard split (s)	20 yard split (s)
40 yard dash time (s)	Pearson Correlation	1	.822**	.938**
	Sig. (2-tailed)		.000	.000
	N	30	30	30
10 yard split (s)	Pearson Correlation	.822**	1	.912**
	Sig. (2-tailed)	.000		.000
	N	30	30	30
20 yard split (s)	Pearson Correlation	.938**	.912**	1
	Sig. (2-tailed)	.000	.000	
	N	30	30	30
5-10-5 time (s)	Pearson Correlation	.726**	.668**	.769**
	Sig. (2-tailed)	.000	.000	.000
	N	29	29	29
broad jump distance (m)	Pearson Correlation	-.503**	-.477**	-.490**
	Sig. (2-tailed)	.005	.008	.006
	N	30	30	30
Vertical jump height (m)	Pearson Correlation	-.328	-.385*	-.415*
	Sig. (2-tailed)	.088	.043	.028
	N	28	28	28
Med ball scoop toss (m)	Pearson Correlation	-.439*	-.349	-.422*
	Sig. (2-tailed)	.020	.069	.025
	N	28	28	28
Relative BS 1RM (kg)	Pearson Correlation	-.576**	-.484**	-.541**
	Sig. (2-tailed)	.001	.009	.003
	N	28	28	28
Relative HT 1RM (kg)	Pearson Correlation	-.679**	-.582**	-.636**
	Sig. (2-tailed)	.000	.001	.000
	N	28	28	28
Relative DL 1RM (kg)	Pearson Correlation	-.441*	-.381*	-.471*
	Sig. (2-tailed)	.019	.045	.011

	N	28	28	28

		5-10-5 time (s)	broad jump distance (m)	Vertical jump height (m)
40 yard dash time (s)	Pearson Correlation	.726**	-.503**	-.328
	Sig. (2-tailed)	.000	.005	.088
	N	29	30	28
10 yard split (s)	Pearson Correlation	.668**	-.477**	-.385*
	Sig. (2-tailed)	.000	.008	.043
	N	29	30	28
20 yard split (s)	Pearson Correlation	.769**	-.490**	-.415*
	Sig. (2-tailed)	.000	.006	.028
	N	29	30	28
5-10-5 time (s)	Pearson Correlation	1	-.506**	-.361
	Sig. (2-tailed)		.005	.059
	N	29	29	28
broad jump distance (m)	Pearson Correlation	-.506**	1	.391*
	Sig. (2-tailed)	.005		.040
	N	29	30	28
Vertical jump height (m)	Pearson Correlation	-.361	.391*	1
	Sig. (2-tailed)	.059	.040	
	N	28	28	28
Med ball scoop toss (m)	Pearson Correlation	-.600**	.142	.404*
	Sig. (2-tailed)	.001	.470	.033
	N	28	28	28
Relative BS 1RM (kg)	Pearson Correlation	-.406*	.133	.130
	Sig. (2-tailed)	.036	.500	.527
	N	27	28	26
Relative HT 1RM (kg)	Pearson Correlation	-.474*	.610**	.387
	Sig. (2-tailed)	.012	.001	.051
	N	27	28	26
Relative DL 1RM (kg)	Pearson Correlation	-.413*	.295	.049
	Sig. (2-tailed)	.032	.128	.813
	N	27	28	26

		Med ball scoop toss (m)	Relative BS 1RM (kg)	Relative HT 1RM (kg)
40 yard dash time (s)	Pearson Correlation	-.439*	-.576**	-.679**
	Sig. (2-tailed)	.020	.001	.000
	N	28	28	28
10 yard split (s)	Pearson Correlation	-.349	-.484**	-.582**
	Sig. (2-tailed)	.069	.009	.001
	N	28	28	28
20 yard split (s)	Pearson Correlation	-.422*	-.541**	-.636**
	Sig. (2-tailed)	.025	.003	.000
	N	28	28	28
5-10-5 time (s)	Pearson Correlation	-.600**	-.406*	-.474*
	Sig. (2-tailed)	.001	.036	.012
	N	28	27	27
broad jump distance (m)	Pearson Correlation	.142	.133	.610**
	Sig. (2-tailed)	.470	.500	.001
	N	28	28	28
Vertical jump height (m)	Pearson Correlation	.404*	.130	.387
	Sig. (2-tailed)	.033	.527	.051
	N	28	26	26
Med ball scoop toss (m)	Pearson Correlation	1	.117	.129
	Sig. (2-tailed)		.568	.530
	N	28	26	26
Relative BS 1RM (kg)	Pearson Correlation	.117	1	.338
	Sig. (2-tailed)	.568		.079
	N	26	28	28
Relative HT 1RM (kg)	Pearson Correlation	.129	.338	1
	Sig. (2-tailed)	.530	.079	
	N	26	28	28
Relative DL 1RM (kg)	Pearson Correlation	.092	.573**	.492**
	Sig. (2-tailed)	.656	.001	.008
	N	26	28	28

		Relative DL 1RM (kg)
40 yard dash time (s)	Pearson Correlation	-.441*
	Sig. (2-tailed)	.019
	N	28
10 yard split (s)	Pearson Correlation	-.381*
	Sig. (2-tailed)	.045
	N	28
20 yard split (s)	Pearson Correlation	-.471*
	Sig. (2-tailed)	.011
	N	28
5-10-5 time (s)	Pearson Correlation	-.413*
	Sig. (2-tailed)	.032
	N	27
broad jump distance (m)	Pearson Correlation	.295
	Sig. (2-tailed)	.128
	N	28
Vertical jump height (m)	Pearson Correlation	.049
	Sig. (2-tailed)	.813
	N	26
Med ball scoop toss (m)	Pearson Correlation	.092
	Sig. (2-tailed)	.656
	N	26
Relative BS 1RM (kg)	Pearson Correlation	.573**
	Sig. (2-tailed)	.001
	N	28
Relative HT 1RM (kg)	Pearson Correlation	.492**
	Sig. (2-tailed)	.008
	N	28
Relative DL 1RM (kg)	Pearson Correlation	1
	Sig. (2-tailed)	
	N	28

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).