Activation of the gluteus maximus during performance of the back squat, split squat and barbell hip thrust and the relationship with maximal sprinting

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Activation of the *Gluteus Maximus* during Performance of the Back Squat, Split Squat and Barbell Hip Thrust and the Relationship with Maximal Sprinting

ABSTRACT

The purpose of this research was to compare muscle activation of the *gluteus maximus* and ground reaction force between the barbell hip thrust, back squat, and split squat and to determine the relationship between these outcomes and vertical and horizontal forces during maximal sprinting. Twelve male team sport athletes (age 25.0 ± 4.0 years, stature 184.1 ± 6.0 cm, body mass 82.2 ± 7.9 kg) performed separate movements of the three strength exercises at a load equivalent to their individual three repetition maximum. The ground reaction force was measured using force plates and the electromyography (EMG) activity of the upper and lower *gluteus maximus* was recorded in each leg and expressed as percentage of the maximum voluntary isometric contraction (MVIC). Participants then completed a single sprint on a non-motorized treadmill for the assessment of maximal velocity, horizontal and vertical forces. Although ground reaction force was lower, peak EMG activity in the *gluteus maximus* was higher in the hip thrust than the back squat ($p = 0.024$; 95%CI = 4 – 56%MVIC) and split squat ($p = 0.016$; 95%CI = 6 – 58%MVIC). Peak sprint velocity was correlated with both anterior-posterior horizontal force ($r = 0.72$) and peak ground reaction force during the barbell hip thrust ($r = 0.69$) but no other variables. The increased activation of *gluteus maximus* during the barbell hip thrust and the relationship with maximal running speed suggests that this movement may be optimal for training this muscle group in comparison to the back squat and split squat.

Keywords: *strength training, bilateral exercises, unilateral exercises, ground reaction force, electromyography*

INTRODUCTION

Axial loaded strength exercises such as the back squat are often regarded as a fundamental component of strength programs designed to increase lower body strength and power (28, 43). Traditional squatting exercises can be further sub-divided into bilateral and unilateral derivatives, although they appear to be equally as efficacious for developing power and lower body strength (29, 41). Nevertheless, these movements do not always improve sprint speed (20). During maximal sprinting, ground contact appears to occur with the hips in a neutral to slightly extended position, with the gluteus musculature shown to be the biggest contributor to hip extension torque (17, 23). This position is not replicated by traditional squatting exercises and this lack of movement specificity between the back squat and sprinting mechanics may explain conflicting reports within the literature regarding its ability to improve running speed (9, 20). Whilst exercises that elicit vertical forces initiate the gluteal muscles (particularly the *gluteus maximus*) in a hips-flexed position, activation is reduced when the hips are neutral or slightly extended (11). If strength and or force production in this position is a limiting factor when sprinting, the back squat may not be the most suitable exercise to prescribe.

Conversely, horizontal force production is a key component in the optimization of acceleration and maximal sprint speed (5, 7, 25, 33, 38) highlighting the importance of incorporating exercises that develop horizontal forces in training programs. Indeed, when used in combination with exercises that promote vertical force production, horizontally orientated exercises have been shown to improve sprint speed and peak power (2, 31). Whether the effect of exercises that utilize horizontal force expression can stimulate improvements in maximal sprint speed without the inclusion of traditional squatting exercises has yet to be elucidated. Recent research, however, has proposed the use of the barbell hip thrust as an alternative means of training the posterior chain musculature of the lower body (11, 12). This exercise has been shown to elicit greater *gluteus maximus* and hamstring activation when compared to the back squat in strength trained females and higher anterior-posterior horizontal forces (12). The barbell hip thrust allows strength to be developed with the hips in an extended position and via a horizontal force production which may be of greater relevance to sprinting (17) (Fig. 1). Although this approach would appear to contravene the training philosophy of specificity, it does conform to the theory of dynamic correspondence; whilst not identical to the activity of sprinting, the barbell hip thrust replicates the muscular patterns, synchronicity and energy production involved during training (40).

*****INSERT FIGURE 1 NEAR HERE*****

Despite recent research (11, 12, 14) comparing the barbell hip thrust with other bilateral strength exercises and its relation to physical parameters including sprint acceleration and jump performance, to our knowledge, there are no comparisons between unilateral strength exercises and the barbell hip thrust. Furthermore, previous research has not determined whether there is any relationship between *gluteus maximus* activity and/or force production during strength exercises or maximal sprinting. The primary aim of the present study, therefore, was to determine the difference between muscle activation and force production during the bilateral squat, unilateral split squat, and barbell hip thrust. A secondary objective was to determine the association of the aforementioned dependent variables with speed, and horizontal and vertical forces during maximal sprinting. The experimental hypothesis was that the barbell hip thrust would elicit higher mean and peak *gluteus maximus* activity when compared to the back squat and split squat and these variables would be more strongly associated with parameters of maximal running performance.

METHODS

Experimental Approach to the Problem

In the first part of this experiment, measurements of ground reaction force and electromyography (EMG) of the *gluteus maximus* were recorded in team sport athletes during three repetition maximum efforts of the barbell hip thrust, bilateral squat and unilateral split squat. Data were then analyzed to determine whether there were any differences between the three different exercises. In the second part of the experiment, participants completed a single maximal sprint effort on a non-motorized treadmill while speed, horizontal force, and vertical force were measured. Data were then analyzed to assess whether there was any association between the variables of muscle activation and force measured during the three different strength exercises with metrics of maximal running performance.

Subjects

Twelve male team-sport athletes volunteered to participate in the study (age 25.0 ± 4.0 years; stature 184.1 ± 6.0 cm; body mass 82.2 ± 7.9 kg) who had 4.0 ± 1.0 years of strength training experience. Subjects had experience in all three exercises, however were utilized to varying degrees by each individual within their own training regimes. Inclusion criteria required participants to be aged between 18 and 35 years, have a minimum of 3 years resistance training experience and able to safely perform each of the three exercises with external load. All participants provided written informed consent and the study was approved by the School of Science and Sport Ethics Committee at University of the West of Scotland.

Procedures

Assessment of three repetition strength

Participants performed three repetition maximum testing on each resistance exercise. Participants performed a standardized warm-up comprising dynamic movement patterns designed to target the gluteal musculature including external resistance via the use of mini-bands. Immediately after the warm-up, participants completed submaximal loads in each of the three exercises to determine the three repetition maximum as advocated by Baechle and Earle (3). This procedure incorporated 5 to 10 repetitions with a light to moderate load, progressing to heavier sets of three repetitions, until the three repetition maximum was determined. The order in which the exercises were assessed was randomized and participants were allowed to self-select recovery time between exercises. The barbell back squat was performed with feet placed slightly wider than shoulder width apart with the bar secured across the upper trapezius musculature (3). Subjects descended until the top of the thigh was deemed parallel to the floor, which was continually cued by the researcher throughout the lifts. The barbell split squat was performed with the same bar position but in a split stance, with the forward foot placed flat on the floor and the rear knee slightly flexed to allow for a heel raised foot positon on the trailing leg. The barbell hip thrust was performed with the subject’s upper back pressed against a weights bench, with feet placed slightly wider than shoulder width apart and the bar positioned across the hips, as advocated by Contreras and colleagues (11).

Maximal voluntary isometric contraction assessment

Participants completed the aforementioned warm up before performing progressive, sub maximal lifts until they felt prepared to perform their three repetition lift as determined during the initial trial. To prepare the subject for electrode placement their skin was shaved using a

Bic® hand razor and sterilized with an alcohol swab to reduce electrical impedance (1, 39). A pair of Ag-AgCl surface conductive gel electrodes (Blue Sensor, Ambu) were then applied with an inter-electrode distance of 2 cm in alignment with the fiber direction of the *gluteus maximus* using positional guidelines described elsewhere (19). Electrodes were attached to both the upper and the lower segment of the *gluteus maximus* on both sides of the body. A line was drawn between the posterior superior iliac spine and the greater trochanter; the upper electrode was placed approximately 5 cm above and laterally to the midpoint of this line given the diagonal direction the muscle fibers course. The lower electrode was positioned approximately 5 cm below and medially to the same line. Electrodes were secured to the skin with tape to avoid movement artefacts (26). Maximum voluntary isometric contraction (MVIC) testing was then performed for the *gluteus maximus* musculature using a standing glute squeeze technique (4, 13). This value was used as a reference for the normalization of data.

EMG and force assessment during resistance exercises

On completion of MVIC testing, participants rested for four minutes before completing the barbell hip thrust, unilateral split squat, and bilateral squat in a randomized order using a basic counterbalanced design. Participants were instructed to complete a three repetition maximum lift for each exercise according to loads previously established with four minutes rest between exercises (3). Two fixed and embedded force plates (AMTI Optima 400600, Boston, USA) were used to measure ground reaction force at a sampling rate of 1000 Hz calibrated according to the manufacturer's guidelines. Participants were instructed to place one foot on each of the force plates for the bilateral squat and barbell hip thrust. For the split squat, participants were required to position their forward leg onto the force plate; for the split squat 3 Rep Max lifts were completed on both legs. A portable squat rack was set up in front of the force plates for the bilateral and unilateral split squats. The barbell hip thrust was performed with the upper back supported on a 17 inch high bench as indicated in Figure 1. An EMG system (Myon AG 320, Schwarzenberg, Switzerland) was used to collect raw EMG signals at 1000 Hz which were filtered using Myon proEMG software. EMG signals for all 3 repetitions of each set were filtered using a 10 to 450 Hz bandpass filter and smoothed using root mean square (RMS) with a 50 millisecond window (15). The EMG data are presented as the mean of the four EMG electrode sites for each of the three exercises to allow comparisons between unilateral and bilateral data. Mean and peak data were normalized to MVIC collected during the pre-assessment glute squeeze. Force plate data are presented as the mean of both legs for each of the three exercises to allow comparisons between unilateral and bilateral data.

Maximal sprint assessment

Following the strength assessments participants rested for 10 minutes before performing a maximal linear sprint on a Woodway Force non-motorized treadmill (Woodway Force 3.0, Waukesha, USA). Participants performed three submaximal warm up sprints to habituate themselves with the treadmill. After a five minute rest they were instructed to complete a maximal effort sprint during which maximal horizontal and vertical forces and velocity were determined.

Statistical Analysis

All statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS 22.0, IBM Corp, Armonk, NY, USA). The distribution of the data were first assessed using a Shapiro Wilk test. One way repeated measure ANOVAs were used to compare mean and peak EMG values between strength exercises. Differences in ground reaction forces were assessed between strength exercises and between legs using a two way repeated measures ANOVA. Any significant main effects were further analyzed by applying Bonferroni corrections for pairwise comparisons. Effect sizes (M1-M2/SD) were calculated using Cohen's d values and defined as small (0.20), medium (0.50) and large (0.80) (11). Pearson product-moment correlations were also used to determine the relationship between peak sprinting velocity and selected variables. Statistical significance was accepted at $p < 0.05$ and 95% confidence intervals (95% CI) are presented with *p* values.

RESULTS

Exercise Loads

The three repetition maximum exercise loads for the barbell hip thrust (157 ± 29 kg, 1.9 ± 0.3 x body mass) were higher than both the back squat (117 ± 39 kg, 1.4 ± 0.3 x body mass, p = 0.001) and the split squat (68 ± 23 kg, 0.8 ± 0.2 x body mass, $p < 0.001$). The three repetition maximum loads for the back squat was higher than the split squat ($p < 0.001$).

Mean Activation

The barbell hip thrust displayed higher mean *gluteus maximus* activation than both the back squat (d = 1.29; p = 0.005; 95% CI = 10 – 55 %MVIC) and split squat (d = 1.24; p = 0.006; 95% CI = 9 – 54 %MVIC, Fig. 2a). There was no difference in mean *gluteus maximus* activation between the squat and split squat (d = 0.05; p = 1; 95% CI = 11 – 13 %MVIC).

*****INSERT FIGURE 2a NEAR HERE*****

Peak Activation

The barbell hip thrust displayed higher peak *gluteus maximus* activation than both the squat (d = 1.08; p = 0.024; 95% CI = 4 – 56 %MVIC) and split squat (d = 1.08; p = 0.016; 95% CI = 6

– 58 %MVIC, Fig. 2b). There was no difference in peak *gluteus maximus* activation between the squat and split squat ($d = 0.07$; $p = 1$; 95% CI = 15 – 19 %MVIC).

*****INSERT FIGURE 2bNEAR HERE*****

<u>Peak Ground Reaction Force</u>

There were no difference in peak ground reaction force between left and right legs in any three of the strength exercises (Fig. 3) Peak force in the right foot was lower in the barbell hip thrust compared to the back squat ($d = 2.98$; $p < 0.001$; 95% CI = 416 – 1012 N) and the split squat ($d = 2.24$; $p < 0.001$; 95% CI = 412 - 740 N). Peak force in the left foot was also lower in the barbell hip thrust compared to the back squat ($d = 2.80$; $p < 0.001$; 95% CI = 596 – 1130 N) and the split squat BSS ($d = 1.80$; $p < 0.001$; 95% CI = 412 - 740 N). Peak force was higher in the back squat than compared to the split squat in the left leg (ES = 0.66; p = 0.019; 95% CI = 45 – 534 N) but not the right leg ($p = 0.18$).

*****INSERT FIGURE 3 NEAR HERE*****

<u>Maximal Sprinting</u>

Peak anterior-posterior horizontal force during sprinting was significantly correlated to peak velocity ($r = 0.72$, $p = 0.008$) but there was no relationship between peak vertical force and peak velocity ($r = 0.232$, $p = 0.47$). Peak force during the barbell hip thrust was significantly correlated with peak sprint velocity ($r = 0.69$, $p = 0.014$). There was a weak relationship between maximal sprint velocity and peak force in both the bilateral squat and the unilateral split squat, but neither reached statistical significance ($r = 0.52$, $p = 0.086$; $r = 0.53$, $p = 0.076$, respectively). Peak *gluteus maximus* activation for each exercise was not correlated with peak sprint speed (all $p > 0.05$).

*****INSERT FIGURE 4 NEAR HERE*****

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DISCUSSION

The objective of the present study was to compare muscle activation of the *gluteus maximus* and ground reaction force between the barbell hip thrust, back squat, and split squat and to determine the relationship between these outcomes and vertical and horizontal forces during maximal sprinting. In agreement with our experimental hypothesis, the barbell hip thrust elicited significantly higher mean and peak *gluteus maximus* activation than the back squat and the split squat when performing three repetition maximum lifts despite a lower peak ground reaction force in this movement. The data supports recent research with female athletes that demonstrated a higher *gluteus maximus* activation in the barbell hip thrust compared to the back squat (12). The present study further extends these findings by demonstrating that peak sprint velocity is significantly correlated with both peak horizontal sprint force and peak barbell hip thrust force.

The results of the present study align with Contreras and colleagues findings and suggest that greater peak and mean activation of the *gluteus maximus* occurs in the barbell hip thrust compared to the back squat. Recent extensive pilot studies by Contreras and colleagues have suggested that the *gluteus maximus* elicits peak EMG activation at the shortest muscle length in hip hyperextension (12). Several researchers have concluded that peak *gluteus maximus* activation during the back squat occurs on the ascendency from the bottom of the lift in a hip's flexed position and that activation increases with load (45). However, Contreras and colleagues (12) found that during isometric holds of both the barbell hip thrust (fully extended position) and back squat (fully flexed position), the former produced significantly greater mean and peak EMG activation in the *gluteus maximus*.

Although there have been numerous studies comparing unilateral to bilateral strength exercises, to the knowledge of the authors, this is the first study to compare a unilateral exercise to the barbell hip thrust. The results showed that while there were no differences between the two squat movements, the barbell hip thrust elicited significantly greater *gluteus maximus* activation than the split squat. The similarity in *gluteus maximus* activation between the squat movements may appear surprising given that peak ground reaction force and the summated total load across both front limbs in the semi-unilateral split squat was higher than in the bilateral back squat (1.6 vs 1.4 x body mass, respectively). Given that an increased load has been shown to increase muscle activation (37), it may be presumed that the additional load during the split squat would have produced higher *gluteus maximus* activation than in the back squat. In this instance, however, the unilateral strength exercise produced similar EMG activation of the *gluteus maximus*. These findings are similar to that of Jones and colleagues (22) who found no difference in *gluteus maximus* activity between unilateral and bilateral exercises despite discrepancies in relative load. Muscle activity was not measured in the support leg in either the present study or in previous work (22) which may explain some of this disparity and highlights the necessity for further research in this area.

Training with traditional squat movements does not always lead to an improvement in maximal sprinting speed (20) although this is often a desired outcome given several studies have demonstrated enhancements in this ability (27, 41). Given that sprint velocity appears to be more dependent on horizontal force production than vertical force production (5, 24, 36), this is perhaps not surprising. Indeed, in the present study, horizontal force production was significantly correlated with maximal sprint velocity. Furthermore, the data presented here demonstrates that peak barbell hip thrust ground reaction force was significantly correlated with maximal sprint velocity. While the vertically oriented back squat and split squat elicited higher ground reaction forces than the barbell hip thrust, the correlation between these values and maximal sprinting speed did not reach statistical significance. Although speculative, this suggests that force production during the barbell hip thrust may be associated with sprint performance in team sport athletes. Furthermore, horizontal anteroposterior based exercises such as the barbell hip thrust may be more effective for improving maximal sprint speed than either squat movement. Indeed, Contreras and colleagues (14) reported that a six week barbell hip thrust training intervention led to improved 20 m sprint times with no improvement in a group completing back squat training. This presents a compelling case that the orientation of force application is an important factor in determining maximal sprint performance. Squats and their derivatives are clearly staples in the field of strength and conditioning, however, understanding how movement mechanics accentuate force development is becoming an important factor in exercise selection.

Despite a positive relationship between horizontal sprint force and maximal sprint velocity, *gluteus maximus* activation was not correlated with maximal sprint velocity. This perhaps is not surprising given Morin and colleagues findings that generation of horizontal force during sprinting was linked with a better activation of the hamstring muscles just prior to ground contact (34). Since the barbell hip thrust and back squat both produce significantly greater *gluteus maximus* activation when compared to *biceps femoris* (11) the lack of correlation between muscle activation and sprint velocity in this study is perhaps to be expected. On the other hand, muscle activation during a hamstring dominant exercise may be more strongly associated with maximal sprint performance.

The assessment of sprint performance in this study was conducted using a non-motorized treadmill. Although this treadmill is regarded as a valid and reliable means of assessing short sprint performance (21) some may question how closely it replicates sprinting outdoors. For example, running on a treadmill eliminates air resistance which is likely to be meaningful during sprinting exercise (42). Furthermore, given the individual is tethered at the hips and has to manually move the treadmill belt with their feet, one could argue this encourages an inclined position, decreasing the involvement of the postural musculature. However, McKenna and Riches (30) demonstrated that individuals use similar sprinting technique on the non-motorized treadmill to over ground sprinting. Furthermore, Morin and colleagues (35) reported that individuals performing sprint accelerations on the non-motorized treadmill produce similar physical and technical movements to outdoor sprint accelerations.

In the present study only two force plates were used, both positioned beneath the feet during the barbell hip thrust exercise. However, at the top of the lift, it is likely that a large portion of the vertical force will be exerted through the bench itself. As such, we would suggest that in future research, an additional plate is placed under the bench or structure supporting the back in order that the ground reaction forces can be more fully quantified. A further potential limitation of the present study was the use of surface EMG to measure muscle activity. The limitations of this technique have been discussed extensively by De Luca (15) and include muscle fiber movement, cross talk from adjacent musculature, extrinsic factors such as volume of subcutaneous fatty tissue and that electrodes may not detect all active motor units. Additionally, EMG peaks may potentially be artefacts given that the EMG signal not only includes muscle movement information but also noise components which are unpreventable despite efforts being made to filter out these unwanted components (15). To reduce potential cross talk, the surface electrodes were positioned within the middle of the muscle belly of the *gluteus maximus* and applied in parallel arrangement to the muscle fibers, with a center to center inter-electrode distance of 2 cm. Further to this, the upper and lower *gluteus maximus* have been shown to activate uniquely (12). However, since in the current study data from these musculature were averaged it has not been possible to determine how the upper and lower fibres correlate with sprinting independently. Despite some of the positive findings in the present study between commonly utilized strength exercises and sprinting, the data obtained is mechanistic in nature therefore the authors suggest future training studies are required to show transference to sprinting and to verify the proposed theories.

PRACTICAL APPLICATIONS

Given maximal sprint speed is correlated with horizontal force production but not vertical production, utilizing exercises which develop force in the horizontal plane may provide superior transfer to sprint based performance. Furthermore, the present study has demonstrated maximal sprinting speed to be correlated with peak force production during the barbell hip thrust but neither of the two vertical squat movements. Applied practitioners can incorporate the barbell hip thrust into their strength programs based on data indicating it has the capacity to elicit greater *gluteus maximus* activity than both the back squat and split squat and that it is more likely to lead to a greater increase in horizontal force production. Based on this data it is proposed that performing anteroposterior strength exercises such as the barbell hip thrust as well as focusing on methods to increase horizontal force during sprinting may be effective in improving maximal sprint performance. During maximal sprinting, it appears toe off at ground contact occurs with the hips in a slightly hyperextended position, which could be a key component as to why barbell hip thrust force production is a better indicator of maximal sprint velocity (17, 23). This is not to suggest that the barbell hip thrust should be used as a replacement for more traditional vertical orientated exercises given they have also been shown to improve sprint performance (28, 44).

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FIGURE LEGENDS

Figure 1. Diagram annotated to show equipment and positional requirements of the Barbell Hip Thrust (permission given by the participant for photographs to be included in this publication)

Figure 2a). Mean *gluteus maximus* EMG activation for all three exercises expressed as a percentage of the maximum isometric voluntary contraction. Data are presented as mean ± standard deviation. * = significantly greater than the back squat. ◊ = significantly greater than the split squat.

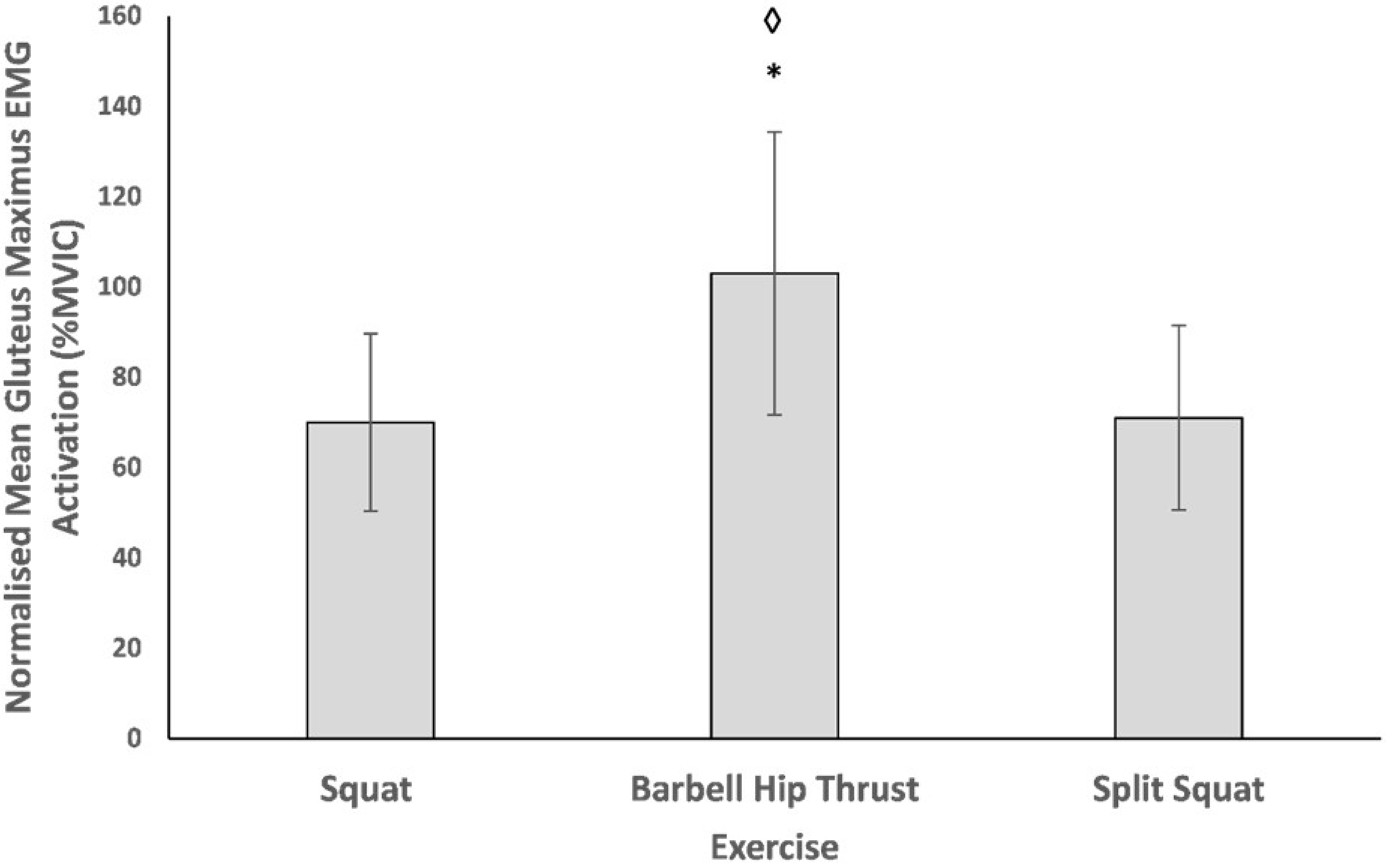
Figure 2b). Peak *gluteus maximus* EMG activation for all three exercises expressed as a percentage of the maximum isometric voluntary contraction. Data are presented as mean ± standard deviation. * = significantly greater than the back squat. ◊ = significantly greater than the split squat.

Figure 3). Peak ground reaction force in each leg for all three exercises. Data are presented as mean ± standard deviation. † = significantly greater than the hip thrust. ◊ = significantly greater than the split squat.

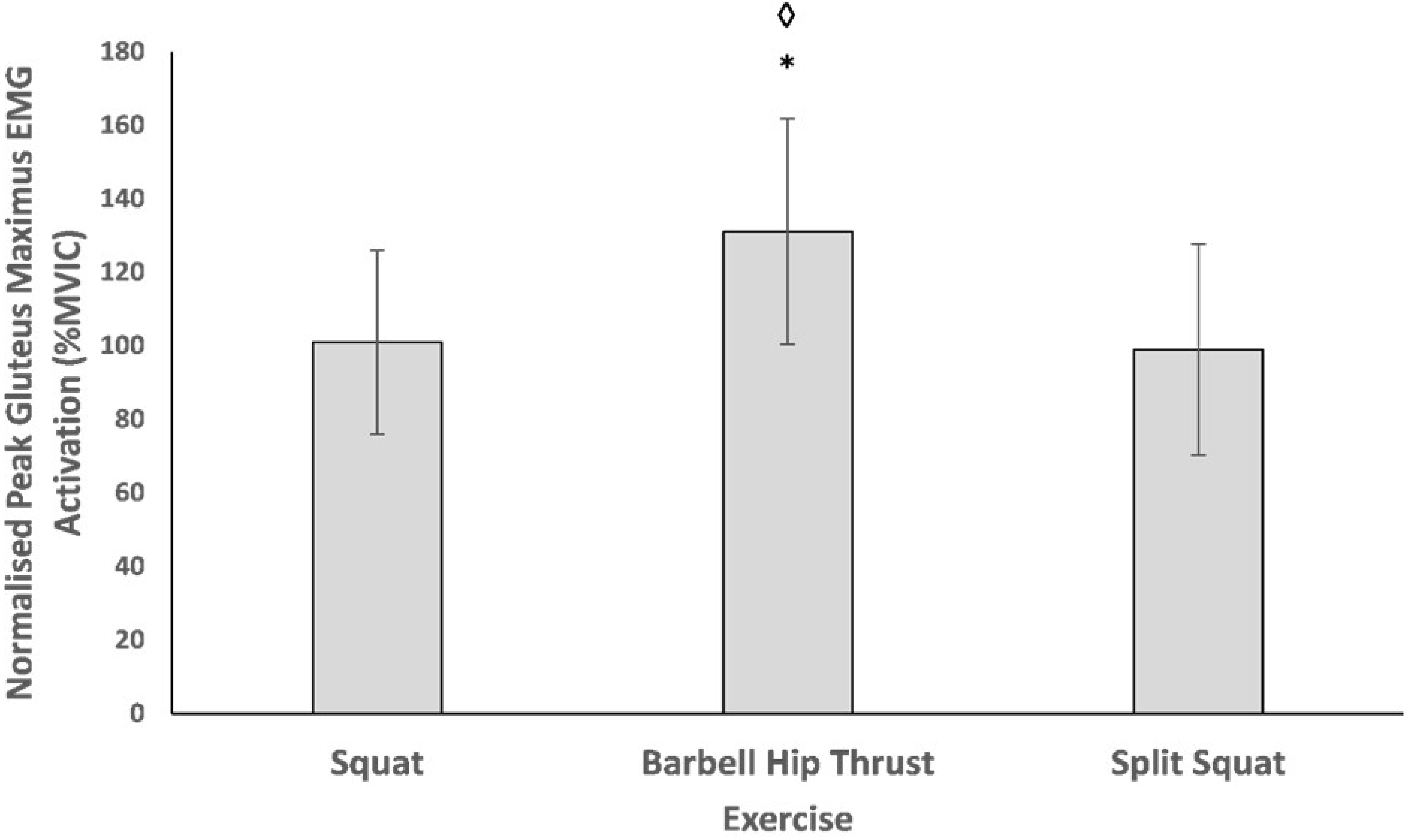
Figure 4). Correlation between peak anterior-posterior horizontal force during sprinting and peak sprint velocity.

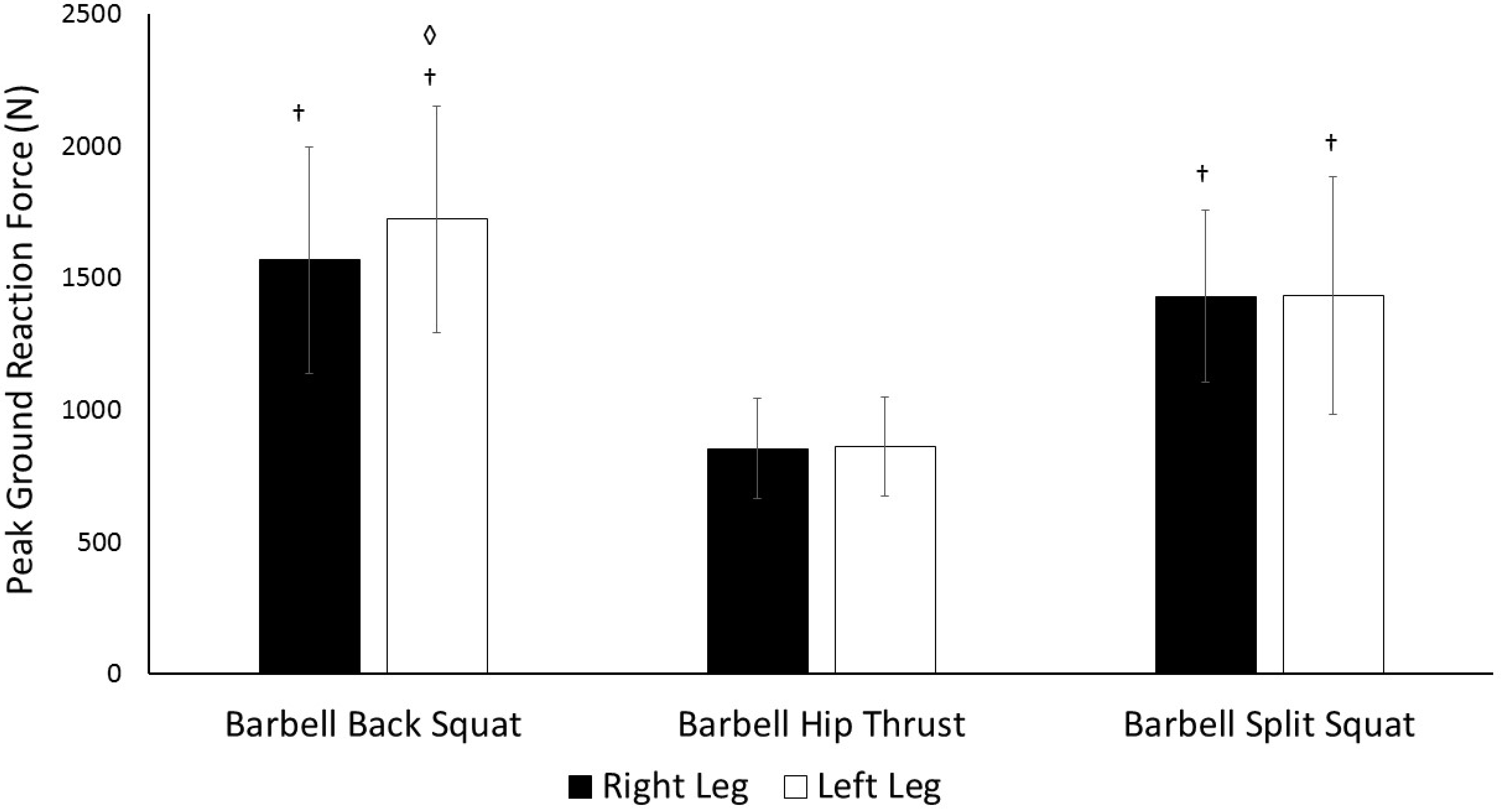
Figure 5). Correlation between peak force during the barbell hip thrust and peak sprint velocity.


Bench ~13"-19" in height as recommended by Contreras (2011)
Trunk musculature braced prior to concentrically raising the bar and throughout the lift
Upper back fixed to bench
TAISHAN
20
Chin tucked to allow safe alignment with spine
Raise bar until torso reaches approx. parallel with floor
Hands evenly spaced on the bar
Feet positioned approx. shoulder width apart
Thick pad is positioned directly in centre of bar to ensure symmetry
Neutral pelvis – no excessive lumbar hyperextension

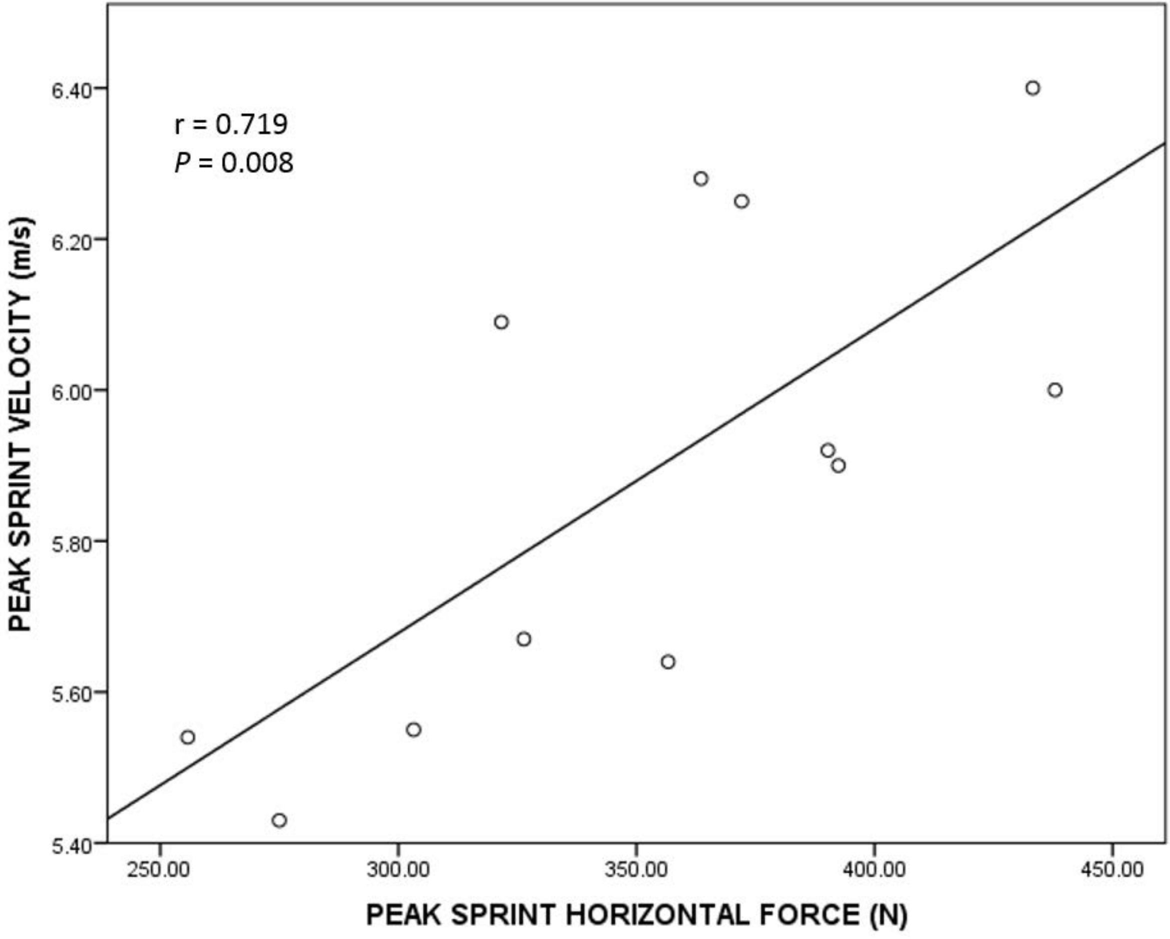


◊
*
160
140
120
100
80
60
40
20
0
Normalised Mean Gluteus Maximus EMG Activation (%MVIC)
Squat
Barbell Hip Thrust
Split Squat
Exercise

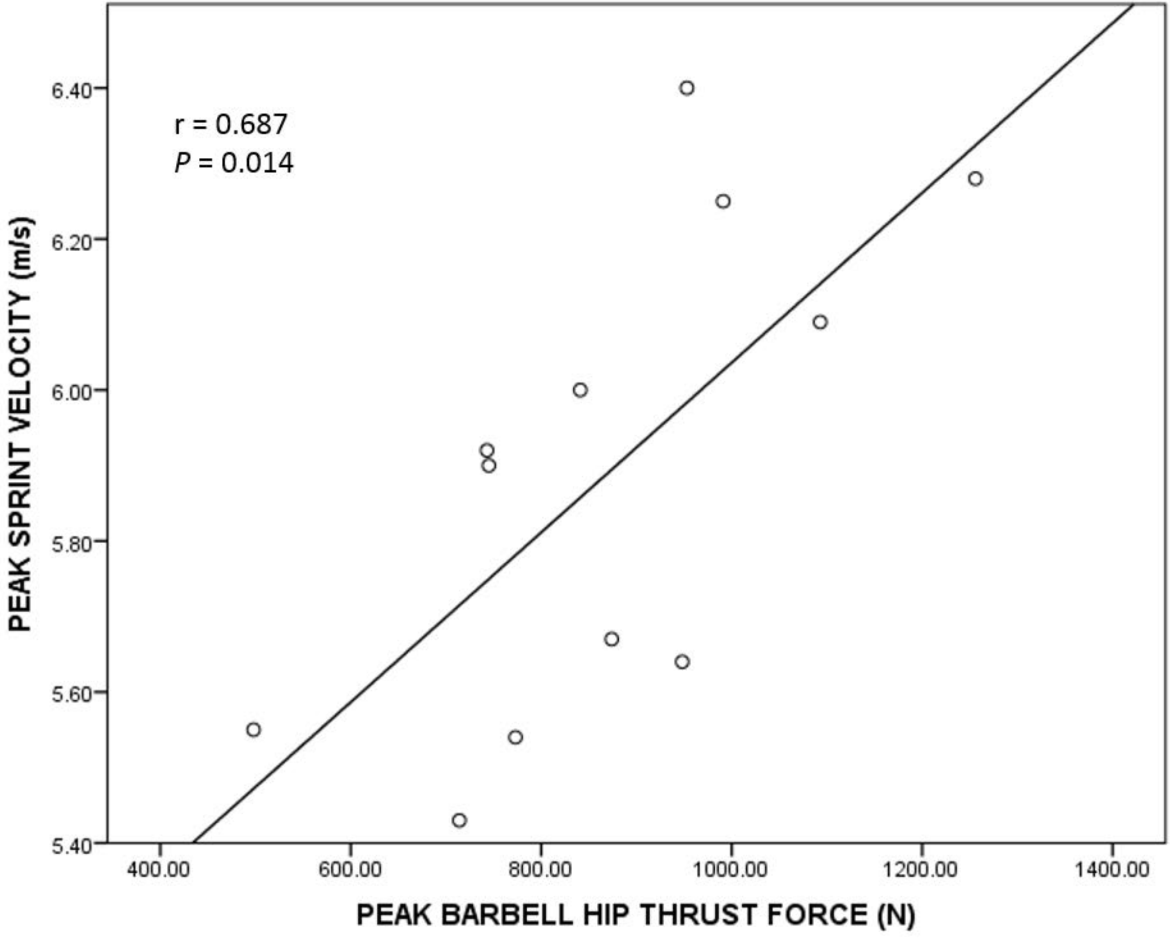

◊
*
Normalised Peak Gluteus Maximus EMG Activation (%MVIC)
0
20
40
60
80
100
120
140
160
180
Squat
Barbell Hip Thrust
Split Squat
Exercise



Peak Ground Reaction Force (N)
2500
2000
1500
1000
500
0
◊
†
†
†
†
Barbell Back Squat
Barbell Hip Thrust
Barbell Split Squat
Right Leg
Left Leg



r = 0.719
P = 0.008
PEAK SPRINT VELOCITY (m/s)
6.40
6.20
6.00
5.80
5.60
5.40
250.00
300.00
350.00
400.00
450.00
PEAK SPRINT HORIZONTAL FORCE (N)



r = 0.687
P = 0.014
PEAK SPRINT VELOCITY (m/s)
6.40
6.20
6.00
5.80
5.60
5.40
400.00
600.00
800.00
1000.00
1200.00
1400.00
PEAK BARBELL HIP THRUST FORCE (N)