Is the rear foot elevated split squat unilateral? An investigation into the kinetic and kinematic demands.

Abstract

The purpose of the study was to determine the unilateral nature of the rear foot elevated split squat (RFESS). Specifically, the production of force by the rear leg was examined to better understand its role, if any, toward successful completion of the exercise. Male volunteers were recruited, (n = 26, age = 23.8 ±4.6 years, mass = 88.1 ±10.7kg, height = 1.79±0.1m), who were recreationally trained and engaged in a structured strength and conditioning program including both bilateral and unilateral exercise and had at least two years supervised training experience. Subjects participated in an incremental five repetition maximum protocol, following familiarisation. Kinetic data was recorded via two independent force plates, one integral to the floor and the second mounted on top of solid weightlifting blocks. Kinematic data was captured through three-dimensional motion analysis. A total of 715 repetitions were analysed, the mean contribution of the lead foot to total vertical force production was 84.36 ±3.6%. An almost certainly small positive correlation (rho = 0.25, CI 0.18, 0.33), was found between percentage of force produced by the lead foot, with increasing exercise intensity. A most likely trivial, non-significant correlation (rho = -0.01, CI -0.09,0.06) with rear foot force production, representing the mass of the rear leg. Data from this study does not indicate that the rear foot contributes to the kinetic demands of the exercise and therefore suggests that the RFESS is a valid unilateral exercise.

Key Words: Strength, Biomechanics, Kinetic, Eccentric, Concentric, asymmetric

Introduction.

Unilateral exercise has been reported as a valid method of developing sports performance qualities such as; leg strength (15, 18), linear speed and change of direction ability (2, 18). Several studies have investigated a range of exercises, that were considered unilateral in nature, including the split squat, step up and rear foot elevated split squat (RFESS) (1, 7, 10, 13, 15, 18). Such exercises have been reported to be of greater specificity for both these sports performance qualities and injury reduction, compared to bilateral exercises (1, 2, 10). The advantages proposed for unilateral exercises are attributable to the narrowed base of support. A reduction of stability, caused by a smaller base of support, creates alternative neuromuscular demands during unilateral exercises, in relation to bilateral exercise. These demands are proposed to both better replicate unilateral sporting tasks, such as changes of direction, and address neuromuscular dysfunction which may lead to decreased injury risk (2, 4, 10).

Unilateral resistance training exercises can be considered those which are completed predominantly by a single limb. Unlike bilateral alternatives such as the back squat, deadlift and weightlifting derivatives. These bilateral exercises are characterized by a parallel stance and significant contribution from both limbs to the execution of the movement. However, exercises labelled unilateral in prior literature, such as the RFESS (10, 13), step up (1, 2) and split squat require an asymmetrical bilateral stance phase either during part, or all the movement. If a limb is in contact with a fixed surface, such as the floor or weightlifting block, then that limb has the capacity to exert a vertical force, which may contribute to the successful completion of the exercise. The exertion of such forces aiding in the execution of the exercise, may then require the task to be considered bilateral rather than unilateral. To address how these exercises may classified and subsequently employed, this paper contends that bilateral exercise is such that both limbs are actively engaged in the execution of the movement, either in a parallel or asymmetrical stance, such as the split squat, for example. Conversely, unilateral exercises are those which are executed with the intention of a single limb to generate the required force, which maybe in either an asymmetrical or unilateral stance. Where a unilateral-asymmetrical exercise is performed, the non-active limb may be balanced on a fixed surface, such as weightlifting blocks in the case of the RFESS, but does not contribute to the execution of the movement. To date, no studies have examined the force production of both limbs, during the RFESS, that it may be considered unilateral-asymmetrical.

The RFESS has been adopted in a number of studies, as a unilateral exercise (10, 12, 14, 15, 18) and has been previously reported as valid and reliable measure of unilateral leg strength at different repetition ranges (5RM – 1RM) (10, 13). Yet without biomechanical analysis of the exercise it is currently unclear if such a classification is entirely accurate. The RFESS is performed in such a way that the lead foot should be solely responsible for successful execution of the exercise (11). The minimisation of vertical force production, by the rear foot, is hypothetically achieved due to its position, elevated and posterior to the trunk. Any vertical ground reaction force (vGRF) exerted by the rear limb would therefore be attributable to that created by the mass of the leg. Previous research by DeForest et al., (6), reported significantly more vGRF was produced during the RFESS (1412.3 ± 258.6 N), than the split squat (1198.6 ± 187.9N) using the same external loads (42.5% of back squat 1RM). This data supports the notion that the elevation of the rear foot reduces the force distributed to that foot, compared with the split squat. The study by DeForest et al., (6), suggests that difference in force produced by the lead leg differentiates the unilateral (asymmetrical) RFESS from the bilateral (asymmetrical) split squat. However, without simultaneous force data, from front and rear limbs, during both exercises this remains unclear. To date, the study by DeForest et al.,(6) is the only study which has reported kinetic data for the RFESS, demonstrating a limited evidence base about the demands of the exercise, and specifically the role of either limb.

It has been outlined that unilateral exercises have a potentially significant role to play in the development of both sporting performance and mitigation of injury risk in athletes (1). However, despite the adoption of a range of exercises considered to be unilateral, including the RFESS, little is known about their kinetic demands. Consequently, strength and conditioning (S&C) coaches, may not be able to incorporate exercises, which are hypothesized to be unilateral in nature, with confidence and clarity of purpose. S&C coaches may select a unilateral exercise for an intended purpose, isolation of a specific limb for strength training, for example. If this exercise selection is in fact asymmetrically bilateral, then the adaptations experienced by the athlete may not be those targeted by the coach and result in a less than optimal performance or potentially increase in injury risk. The purpose of the study was, therefore to assess, through examination of the kinetic and kinematic demands of the exercise, the hypothesis that the RFESS was unilateral in nature. If the hypothesis is accepted, then S&C coaches can adopt the RFESS as a valid unilateral-asymmetrical exercise, which has been demonstrated to be efficacious in both measuring (7, 10, 13) and developing (18) lower limb performance.

Methods.

Experimental Approach to the Problem

The hypothesis that the RFESS was a unilateral exercise, was investigated in two ways. The first method investigated the relationships between increasing exercise intensity and the production of vGRF by the both limbs and the relative contribution of both to total vGRF. The second approach investigated intra-repetition kinetics, specifically time at peak rear foot vGRF relative to vertical displacement within repetitions using trials at maximal intensity (100% 5RM) only. Should peak rear foot force be achieved prior to maximal negative vertical displacement of the bar, then this limb was considered not to be contributing to successful execution of the exercise. An incremental five repetition maximum protocol was adopted, as described by Helme et al., (7). Kinetic data was collected using two independent force plates, placed under both lead and elevated rear limbs, kinematic data was recorded via three-dimensional (3D) motion capture.

Subjects

With institutional ethical approval, 26 male volunteers were recruited, (age = 23.8 ±4.6 years, mass = 88.1 ±10.7kg, height = 1.79±0.1m). All subjects were engaged in a structured S&C program including both bilateral and unilateral exercise and had at least two years supervised training experience. Subjects were excluded from the study if they have experienced a lower limb injury within the previous six months or have had an injury requiring surgery to either limb previously.

Procedures

Participation in this study required the subjects to attend a testing facility on two occasions. The first to perform basic anthropometric measures and familiarization with the exercise protocol and the second required the subjects to perform an incremental RFESS 5RM test on both limbs. Effective technique for the RFESS was adopted from Helme et al., (7) as follows;

- Subject maintained balance throughout the exercise,
- The heel of the front foot maintained contact with the ground throughout the exercise.
- Only the toe of the shoes of the rear foot were in contact with the force plate
- The subject maintained a neutral posture, and hip angle of approximately 180°, from the rear leg.
- The knee of the rear limb descended below the height of the lead limb knee and achieved a depth approximately equal to the height of the ankle on the lead limb.

If a subject adopted a bilateral stance at any point within the trial or paused longer than two seconds between repetitions, this was considered a failed attempt. The subjects were positioned with their lead foot on a force platform integral within the floor, under their hips with the rear foot elevated behind them where their toes were placed on the force plate, as shown in Figure 1. A minimum of two minutes recovery was observed where trials were performed using opposing limbs, in the case of the same limb being used a minimum of three minutes was applied. The subjects were instructed to wear appropriate sports footwear, which were consistent across all trials.

Insert figure 1 about here*

Kinetic data was collected using two independent force plates (Kistler 9827C, Kistler Group, Winterthur, Switzerland) placed under the lead and elevated rear foot, as illustrated in Figure 1. Configuration of the testing procedure was prescribed to reflect the anticipated constraints of typical field environments. The rear force plate was mounted on weightlifting blocks, 40cm in height, placed at distance individualised for each subject, allowing them to perform the exercise as prescribed. Rear foot elevation was consistent for all subjects (40cm) as this was previously employed (6, 7). The standardized elevation was adopted as the capacity to provide each participant with a precisely configured platform based on limb length, was not feasible in either lab or field setting. A minimum of two minutes rest between trials, on either limb was taken, during data collection and a maximum of five maximum trials per limb was permitted. Each limb was considered independently, and a 5RM value was determined for each leg.

Three-dimensional (3D) kinematic data was collected using Qualysis track manager captured using 10 Opus cameras (Qualysis AB, Gothenburg, Sweden). Reflective markers were placed at either the end of the barbell, in the medio-lateral plane, the mean position of these markers was calculated to represent the true position of the bar and subsequent motion. Data was extracted and input into Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and placed in a fourth order low pass Butterworth filter (10Hz). Additionally, data from all maximal trials only were normalized to 101 time points. Data filtering and normalization were both conducted using Biomechanics toolbar, (19). All further data processing and analysis was performed using R (17), with a code written specifically for this study.

The initiation of a repetition was defined as five consecutive increases in the magnitude of negative vertical bar displacement and terminating at the time frame where five consecutive decreases in positive vertical bar displacement occurred (7). This analysis was performed on the kinematic data taken from 3D motion capture at 250Hz. Within each repetition the eccentric and concentric phase were considered to end and start respectively at the time point where maximal negative vertical bar displacement occurs.

Statistical Analyses

Analytical approaches were differentiated between intra and inter repetition outcomes. A Shapiro-Wilks test of normality and Levene's test of variance was performed on all variables prior to analysis to determine the appropriate statistical tests to be selected.

Inter-repetition analysis

Correlation analysis was performed on relative exercise intensity, as determined by the percentage of 5RM (%5RM) with, lead limb vGRF, rear foot vGRF and the percentage contribution of the lead foot to total vGRF. This analysis was performed to firstly determine if there was a significant relationship between increasing load and vGRF produced by the either the rear or lead limb. Secondly if the relative contribution of either limb changed with increasing intensity. If the hypothesis is correct and the RFESS is a unilateral-asymmetrical exercise, greater amounts of vGRF should be observed in the lead but not rear limb. Such a finding would be observed through a positive correlation between both lead limb vGRF production and its relative contribution to total vGRF production, with %5RM. This would be accompanied by an unclear or trivial correlation between rear foot vGRF and %5RM. These observations would indicate that the contribution of the lead limb increases with greater external load and a consistent vGRF exerted by the rear foot which represents the constant mass of the leg.

Pearson's product moment (PPM) was selected for correlation analysis, however, if a Shapiro-Wilks test of normality was significant for one or more variables a Spearman's rank order (SRO) correlation, was applied. A magnitude-based decisions approach was adopted to report findings. Cohen (5) identified an *r* value of 0.1 as the smallest clinically important correlation, therefore this was set as the threshold of analysis for inferences in all correlational analysis. The magnitude based decisions were analyzed, based on the probability that the correlation observed was greater than 0.1 and classified as follows; <0.5% almost certainly not; 0.5-5% very unlikely; 5-25% unlikely; 25-75% possibly; 75-95% likely; 95-99.5% very likely; >99.5% almost certainly, where there is greater than 5% chance of both a negative and positive result, the inference will be deemed unclear. (8).

Further assessment of the interaction between rear foot vGRF and intensity was performed on repetitions, based arbitrarily on relative percentage of 5RM, in the following groups; 0-50%, 51-60%, 61-70%, 71-80%, 81-90%, 91-99% and 100% (5RM load). Such boundaries were considered to be representative of differing levels of intensity as might be used by coaches in prescribing exercise at different repetition ranges. Between group differences of both rear foot vGRF and vGRF force distribution to the lead foot were performed. As multiple differences were possible between different categories of repetitions an ANOVA was used, where data was of equal variance. Tukey's honest significant difference (HSD) pot hoc test followed to investigate specific differences between individual groups. If the data was not of equal variance a Kruskal-Wallis analysis was performed, coupled with a Dunn's post hoc test, if significance was observed.

Intra-repetition analysis

The time to peak rear foot vGRF (R- $vGRF_{max}$) and time to peak negative vertical displacement of the bar (P-vdisp), were extracted from time normalized data, from all maximal trials (Repetitions, n=400). Significant differences between R- $vGRF_{max}$ and

P-vdisp were assessed using, either an independent T-test or Wilcoxon rank sum test, subject to the outcome of a Shapiro-Wilks. Proportional bias between time to P-vdisp and R- $vGRF_{max}$ was determined through a Bland-Altman test. This test analyzed the relative consistency of occurrence of R- $vGRF_{max}$ with respect to the occurrence of P-vdisp. A critically significant difference was set as one standard deviation of time to P-vdisp. Finally, relationship between P-vdisp and R- $vGRF_{max}$ would be examined by correlation analysis

As the study employed a range of statistical approaches the effect sizes (ES) for each are summarized in table 1. All ES were classified according to Cohen's guidelines (5).

****insert table 1 about here *****

The hypothesis that the RFESS is a unilateral exercise would be accepted if non-significant differences were found between the rear foot vGRF production and distribution of vGRF production at different intensities. Secondly if R-$vGRF_{max}$ was found to have occurred prior to P-vdisp.

Results.

The mean 5RM for both legs, from all subjects, was 84 ±16.8kg, when normalised to body mass, mean relative strength was 0.96 ±0.18 kg/kg. The mean asymmetry for 5RM absolute strength was 101.08 ±10.13%, calculated using the percentage difference method (3).

A total of 715 repetitions were analyzed, descriptive statistics of which, both overall and according to relatively exercise intensity, are displayed in Table 2.

Insert table 2 about here

An almost certainly small positive correlation (rho = 0.25, CI 0.18, 0.33, Adjusted R^2 =0.08, p = <0.001), was found between exercise intensity (%5RM) and the contribution of the lead foot to total vGRF. This indicates a reduction in the contribution of the rear foot to total vGRF as external load increases. This is further supported by the data represented in Figure 2 which shows a non-significant (p= > 0.05) trivial relationship between rear foot vGRF production when normalised to body weight. Analysis of the relationship between percentage of 5RM load and vGRF production of the rear foot found either likely (rho = -0.07, CI -0.15,0.00), or most likely trivial, non-significant (rho = -0.01, CI -0.09,0.06, Figure 2), correlations, when measured in either Newtons or normalized to body weight, respectively.

Insert figure 2 about here

The summary of categorized data in Figure 3 and table 2 demonstrates similar findings, indicating an increase in lead foot vGRF production, ranging from 1.21 BW to 1.61 BW, but similar outputs (≈0.3 BW) for rear foot vGRF in all of the intensity bands. A Levene's test of variance was performed on mean rear foot vGRF production in the intensity categories of the RFESS 5RM. This test was found to be significant (p = <0.01), therefore a Kruskal-Wallis Rank Sum Test was performed on the mean vGRF (BW) production of the rear foot between these intensity catergories. Significant small differences were observed (df = 6, chi-squared = 20.236, p = 0.002, Epsilon squared = 0.03). Post-hoc Dunn's test was performed and results indicate that there was significant differences in mean vGRF production when loads were less than 50% of 5RM, however, the sample was small for this category (n=10) representing 1.4% of the total sample. Such a small number of data points does not represent a critical mass of information on which to make inferences about this level of intensity. Further inspection of the data suggests that mean vGRF production between 90-99% is significantly different from other intensity categories. However, data presented in Table does not support this difference.

insert figure 3 about here

Vertical displacement was found to have an almost certainly small negative correlation (rho = -0.29, CI -0.36, -0.22) with exercise intensity (%5RM), showing decreasing range of movement with increasing load. Post-hoc analysis observed a moderate effect size for differences between intensity categories (Epsilon-squared =0.125). Further analysis, through a Dunn's test observed that significant differences (p= <0.01) existed in displacement at 100% 5RM and repetitions at 0-50%, 50-60% and 70-80% but non-significant differences (p=>0.05) for repetitions in higher intensity categories. A trivial effect size was found for differences between 100% 5RM and each of the submaximal categories, with both significant and non-significant differences.

Intra-repetition analysis

P-vdisp occurred at 50.84 ± 6.38 AU's, this was preceded by R-$vGRF_{max}$ occurring at 28.87 ±11.68 AU's and followed by peak lead foot vGRF (L-$vGRF_{max}$) at 55.76 ±33.32 AU's. A Wilcoxon rank sum test found a possibly large effect size for difference between time at R-$vGRF_{max}$ and P-vdisp (r = -0.58, CI -0.23, -0.04). Such data suggests that peak vGRF, produced by the rear foot, is during the negative eccentric phase and not in the positive, concentric phase of the RFESS. An almost certainly moderate positive correlation (0.36, CI 0.26, 0.43) was found between these variables suggesting that there was a relationship between the time at which either achieved peak values.

*** Insert table 3 about here***

*** Insert figure 4 about here***

An illustration of the relative time to peak values is given in Figure 4, this furthermore demonstrates the variability of these two measures. The mean CV for vertical displacement was 5% for all 101 time points, compared to 39% for rear foot vGRF production. This suggests that, the time to R-vGRF$_{max}$ is typically prior to P-vdisp, which is stable at ≈ 50% of repetition time. However, the high variability of the peak rear foot data means the relative time at which this occurs is not stable, leading to a lack of certainty in its biomechanical role during this phase of the exercise. Finally a Bland-Altman analysis of bias between occurrence of P-vdisp and R-vGRF$_{max}$ found a critical difference of -12.35, (CI -34.63, 9.93), which exceeds one standard deviation of P-vdisp (6.38) and was therefore accepted as statistically significant. This finding indicates that R-vGRF$_{max}$ systematically occurs prior to P-vdisp.

Discussion.

This study hypothesized that, although adopting a bilateral stance, the RFESS is a unilateral exercise. More specifically, the configuration of the exercise is such that it is a unilateral-asymmetrical exercise, whereby the the lead limb is solely responsible for the vertical motion observed. To date, this is the first study to examine the role of the front and rear limbs during the RFESS and determine its classification as a unilateral task. The data observed in this study is in agreement with the hypothesis that the RFESS is a valid unilateral strength exercise.

Between repetition analysis observed that an almost certainly positive correlation (rho = 0.25, CI 0.18, 0.33), exists between increasing percentage of 5RM and contribution of the lead foot to total vGRF production. This finding would suggest that the increasing vGRF demand of higher external loads was met by the lead leg and not the rear leg. Such an observation is supported by the summary data included in Table 2 and further coroborated by the non-significant, trivial relationship between rear foot vGRF production and increasing percentage of 5RM load (rho = -0.01, CI -0.09,0.06). A Kruskal-Wallis assessment of rear foot vGRF (BW) production did find a small significant difference between intensity categories (p = 0.002, Epsilon squared = 0.03). Dunn's test identified that rear foot vGRF production between 90 and 99% was significantly different from other exercise intensity categories, yet these differences ranged between -1% and 3% of mean total vGRF. The discrepency in vGRF of 0.02 BW between intensity categories was considered unlikely to differentiate between successful or unsuccessful execution of the RFESS and therefore not to be of practically meaningful difference.

Further analysis of the time-normalized, intra-repetition kinetics during the RFESS, identified a significantly large difference in the occurrence of peak vGRF produced by the rear foot when compared to time at peak negative vertical bar displacement. This observation was further supported by correlational and bias analysis, indicating that the rear foot produced peak vGRF, during the initial, negative, eccentric phase of the exercise. If maximal vGRF, from the rear foot, was produced during the eccentric phase, then only sub-maximal force was exerted during the concentric "lifting" phase of the exercise (9). Successful performance of the exercise was deemed to be descending toward the floor until the rear knee near reached the approximate height of the lead limb's lateral malleolus and returning to the original stance phase. During the initial downward phase, the mass of the participant, plus external load, succumbs to gravity in order to descend. Eccentric muscular contractions, apply vGRF to act as a braking force, allowing for negative acceleration at rates slower than gravity. Therefore, it may be considered that the rear limb may play a role in the application of an eccentric braking force.

Considering the exertion of vGRF, expressed through the rear foot, the mass the of the limb should be accounted for. Plagenhoef et al., (16), identified the mass of a lower limb as being ≈16% of body total mass. Evidence in this study suggests that within a repetition the mean vGRF exerted by the lead foot remains consistent at 84.36 ±3.6% of total vGRF production. Whilst it may be possible that that rear leg exerts an eccentric force, when the mass of leg is considered (≈15% body weight), the amount of force applied to the descending object may be negligible. Furthermore, to ascend from the maximal point of negative displacement, forces greater than acceleration due to gravity must be applied (9). This phase, therefore, is the key to successful performance, as it requires the greatest application of vGRF. Data from this study demonstrated, that R-$vGRF_{max}$ is likely produced prior to the concentric phase of the exercise. Furthermore, the magnitude of force applied by the rear foot, in excess of the mass of the leg, is unclear. These observations support the notion that the rear leg does not contribute to the successful execution of vertical displacement, in the RFESS. The vGRF exerted by the via the rear foot may be limited to the stabilisation of the rear limb. Consideration of evidence within this study, both between repetitions at different intensities and within maximal repetitions, supports the acceptance of the hypothesis that the RFESS is a unilateral exercise.

The protocol employed in the current study, required subjects to descend to a minimal acceptable level but did not specify a precise and uniform displacement for all subjects, in all repetitions. As such, variability between and within trials was evident, as demonstrated in table 2 and by a significant, yet small negative correlation between vertical displacement of the bar and increasing percentage of 5RM. All repetitions included within this study, adhered to the protocol outlined, achieving a depth at least equal to the height of the lead limb lateral malleolus. However, as the minimum distance only was prescribed, subjects exceeded this mandate to a greater magnitude with lighter loads. Previous studies have prescribed different methods of determining repetition depth. McCurdy et al., (13) prescribed subjects achieved an angle of 90° between femur and tibia, where DeForest et al., (6) required the knee of the rear leg to touch the ground. The method employed by this study and that of Helme et al., (7) was judged to be most reflective of current practice within S&C, most easily applied by test administrators to visually check squat depth and inclusive of subjects who were not able to achieve the displacement required by DeForest et al., (6). However, future application of this protocol would benefit from clear guidance and feedback to the subjects regarding consistent performance of each repetition, to the required depth.

The subjects engaged in this study represent a relatively homogenous sample, being of similar age, gender and training experience. All participants had a minimum of two years resistance training experience, including unilateral training and had been familiarized with the RFESS prior to testing. The consequence of such a relatively small (n=26) and homogenous sample, means the extrapolation of the findings to wider, more heterogenous populations could not be assumed without further research. Kinematic data determining the displacement of the bar was derived from the mean position of two markers on opposing ends of the barbell. Weightlifting bars have an inherent elasticity which is advantageous during tasks such as the clean, that utilise heavy loads moving rapidly. Whilst no such elasticity was observed during data collection, this may mean that the mean of the two marker positions is not an accurate representation of the centre of the bar. Furthermore, the research design of the current study, employed the extraction of data from an incremental protocol. This resulted in an uneven distribution of repetitions at different percentages of 5RM. While the current study analysed a large sample of repetitions, it did not target an even distribution of repetitions at each intensity category. A more focused protocol, specifically collecting trials at set intensities, would have allowed a more even distribution of repetitions across the spectrum of loads.

Previous literature (1, 2, 10) has proposed that unilateral strength training exercises, such as the step up (2) have both performance and injury reduction benefits. However, no studies had previously investigated unilateral leg strength exercise to accurately classify them as such. This study was the first to determine that the lead limb is solely responsible for vGRF production resulting in successful completion of the RFESS.

Practical Applications.

This study hypothesized that, although adopting an asymmetrical stance with both feet, the RFESS is a unilateral exercise. More specifically this study contended that exercises may be categorized both by the points of contact with a fixed surface and the contributions toward vGRF, as such the RFESS is a unilateral-asymmetrical exercise. Data from this study suggests that there is negligible contribution from the rear foot during the concentric phase of the RFESS at sub-maximal and loads, supporting this hypothesis. Exercises proposed to be unilateral in nature, such as the step-up, split squat and RFESS have been shown to effective in developing athletic ability. However, this is the first study to date to investigate the role of either foot to accurately classify an exercise as unilateral in nature. The evidence, in this study, therefore, suggests that the RFESS may be employed by S&C coaches, as a unilateral strength exercise to determine and enhance the athletic qualities, of their athletes.

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Figures

Figure 1: Demonstration of the configuration for data collection in the RFESS 5RM


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Figure 2: A Scatter plot demonstrating the correlation between exercise intensity and vGRF (BW) production of the rear foot

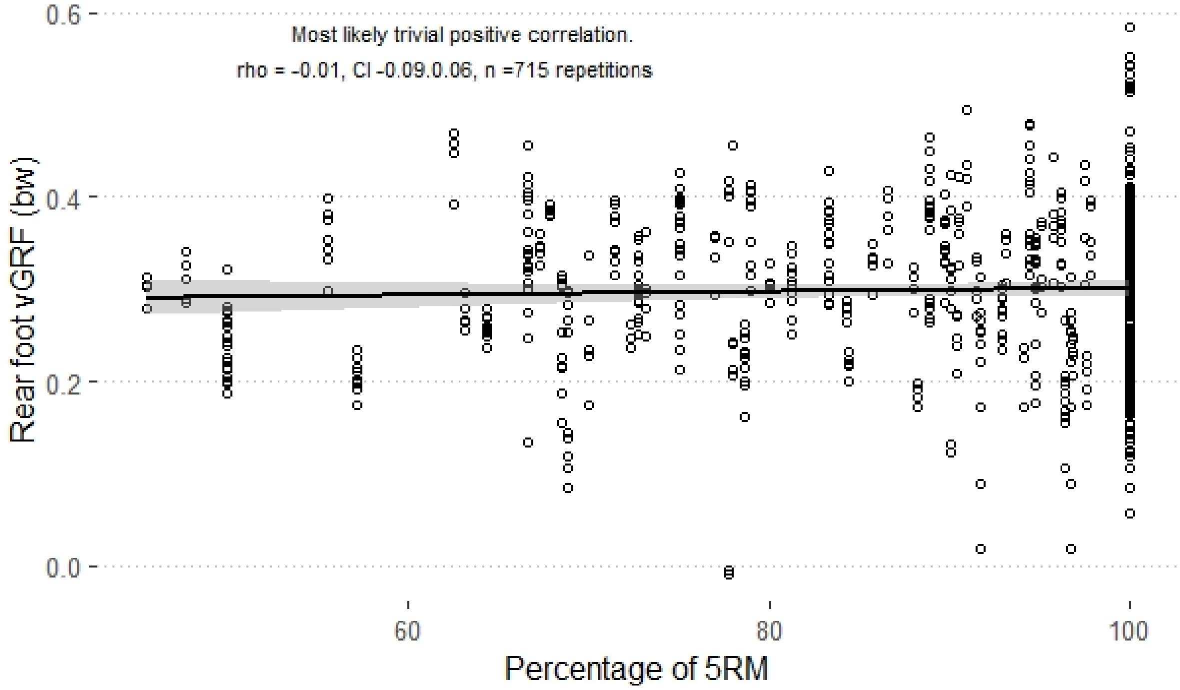
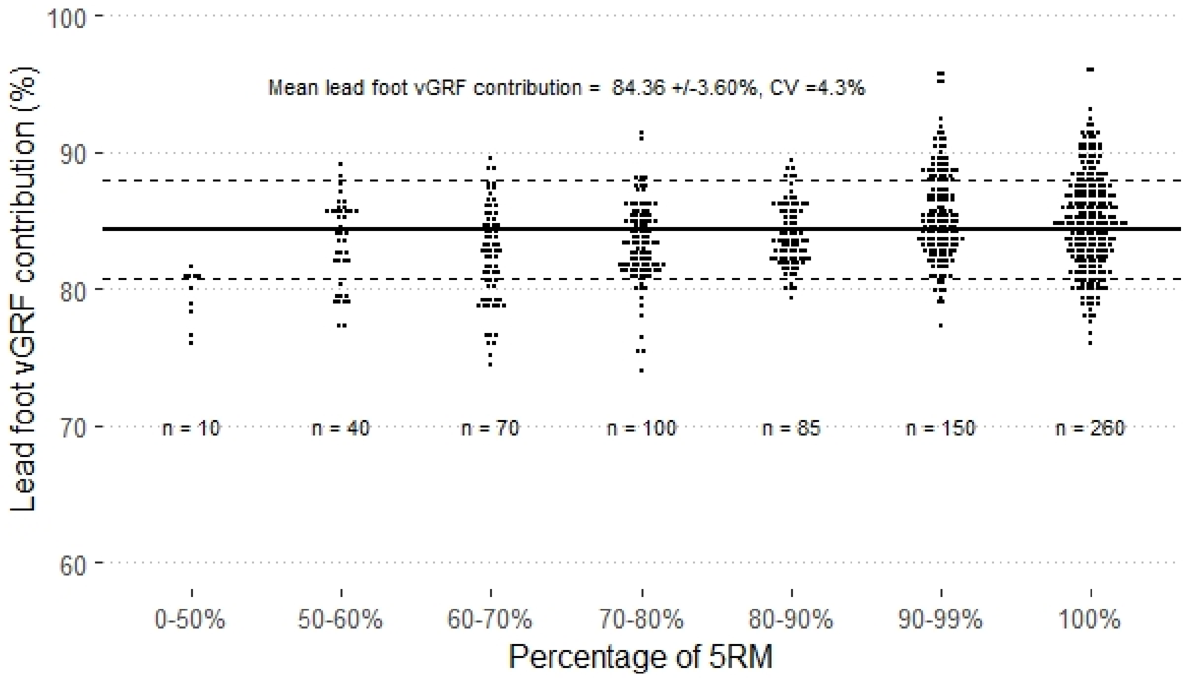
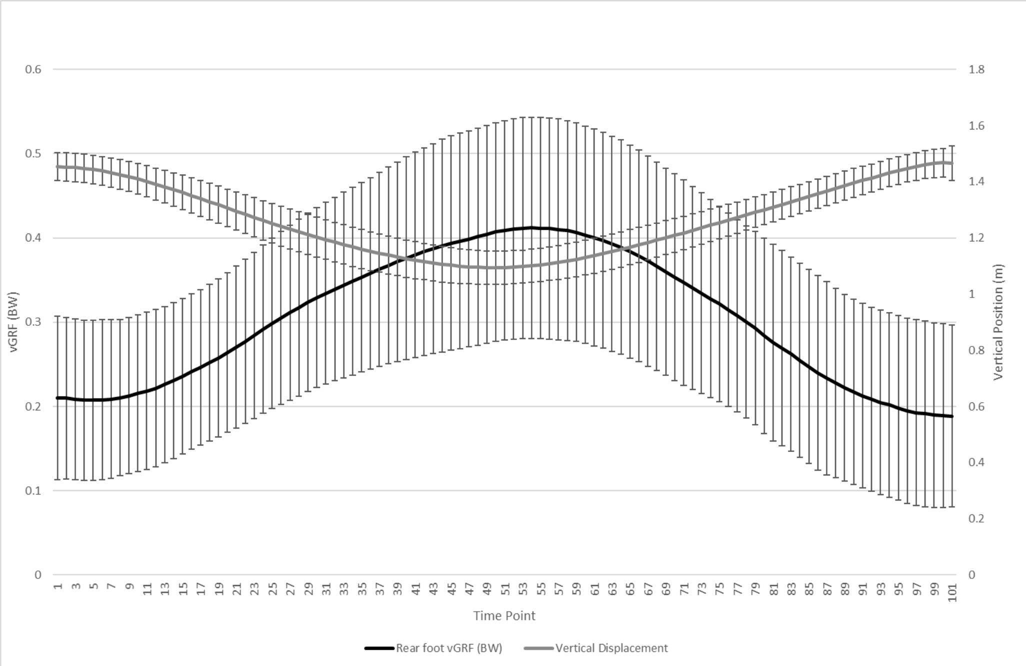

Most likely trivial positive correlation.
rho = -0.01, CI -0.09.0.06, n =715 repetitions
Rear foot vGRF (bw)
0.6
0.4
0.2
0.0
60
80
100
Percentage of 5RM

Figure 3: A plot depicting the mean vGRF (N) contribution of the lead foot to repetitions of the RFESS 5RM, including distribution into arbitrary categories of exercise intensity



Mean lead foot vGRF contribution = 84.36 +/-3.60%, CV =4.3%
Lead foot vGRF contribution (%)
100
90
80
70
60
n = 10
n = 40
n = 70
n = 100
n = 85
n = 150
n = 260
0-50%
50-60%
60-70%
70-80%
80-90%
90-99%
100%
Percentage of 5RM

Figure 4: a graphical representation of mean (±1SD) vertical bar position and rear foot vGRF (BW), during a 5RM RFESS, time normalised to 101 points.



0.6
0.5
0.4
0.3
0.2
0.1
0
vGRF (BW)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Vertical Position (m)
Time Point
Rear foot vGRF (BW)
Vertical Displacement

Tables

Table 1: A comparison of effect sizes used to interpret statistical analysis

	Trivial	small	moderate	large	very large	Practically perfect
Tests of differences between groups (T-test, Wilcoxon rank sum test)	<0.1	0.1 < 0.30	0.3, < 0.5	≥ 0.5		
Correlations (Pearson product moment, Spearman rank order)	<0.1	0.1 < 0.3	0.3 < 0.5	0.5 < 0.7	0.7 < 0.9	>0.9
ANOVA or Kruskal-Wallis		0.01 < 0.08	0.08 < 0.26	≥ 0.26		

Table 2: Descriptive variables of the RFESS at different levels of exercise intensity.

Intensity category	No of repetitions	Mean vertical displacement (m)	Mean rear foot vGRF (BW)	Mean lead foot vGRF (BW)	Mean lead foot vGRF contribution (%)
Total	715	0.40±0.06	0.30±0.09	1.54±0.23	84.29±3.46
50-60%	40	0.43±0.07	0.26±0.06	1.22±0.11	83.42±3.42
60-70%	70	0.42±0.06	0.30±0.09	1.37±0.13	82.44±3.54
70-80%	100	0.40±0.06	0.30±0.10	1.48±0.18	83.33±2.96
80-90%	85	0.39±0.05	0.32±0.06	1.52±0.18	83.94±2.26
90-99%	150	0.38±0.05	0.30±0.09	1.68±0.21	85.51±3.46
100%	260	0.39±0.05	0.30±0.09	1.61±0.19	84.91±3.53