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Comparison of muscle activity and kinematic parameters between bilateral squat and unilateral squat

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1. Abstract

The purpose of this study was to compare the differences in muscle activity and kinematic parameters between 4-RM bilateral squat and equal load as for one leg in the unilateral squats. Fourteen resistance-trained males (age 23 ± 4 years, body mass 80,45 ± 8,52 kg, height 1,81 ± 6 cm) participated in this study. Barbell kinematics and EMG activity of rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semimembranosus, gastrocnemius, soleus, gluteus medius, gluteus maximus, external abdominal oblique and erector spinae were measured in each repetitions during the squat exercises. Results show that total lifting time was longer and velocity was lower in the bilateral squat ($P \leq 0.001$). In the bilateral squat a generally higher activation was found in the three measured quadriceps muscles (rectus femoris, vastus medialis, vastus lateralis), biceps femoris (ascending phase) and the erector spinae (ascending phase)($P \leq 0{,}037$). In the unilateral squat foot forwards a significant higher activation was found for the semimembranosus (descending phase)($P=0{,}003$). In addition some muscles show a pattern of increased EMG from repetition 1-4 ($P \leq 0{,}034$).These results may indicate a better strength gain in the quadriceps muscles, biceps femoris and erector spinae when performing the bilateral squat. There is a greater power development in the unilateral squats (F= M x A), in addition the unilateral squat foot forwards is probably a better exercise for strengthening the semimembranosus.

Key words: *EMG, kinematics, ascending phase, descending phase.*

2. Introduction

Bilateral exercises such as the squat are normally implemented as an important part of resistance training programs. This is to build foundational strength, especially for untrained individuals. However unilateral exercises is not seen as a core exercise but works as an assistance exercise, this often leads to avoidance of unilateral exercises among untrained. One of the reasons this occur is the lack of research on unilateral exercises and their potential to improve strength and power. Despite this the theory of bilateral force deficit show that the mechanical output per leg is less in two-legs than in one-leg(Baechle & Earle 2000; Bobbert, Graaf, Jonk, Casius, 2006). This so called bilateral force deficit has been attributed to a reduced neural drive to muscles in two-leg performances (Ibid). Regardless of the lack of scientific data, there are many skills that requires great power development in the lower extremity and in a unilateral movement pattern (running, kicking, changing running direction, throwing, hitting, vertical and horizontal leaps). These exercises are performed with a unilateral weight-bearing phase and to most effectively improve performance, resistance training should closely resemble the mechanics and forces required to perform the necessary skills in a particular sport (Baechle & Earle, 2000). There should be a natural link between specific resistance training and the skill required (Young, 2006).

The bilateral squat is preferred to unilateral exercises when building foundational strength. Despite this, research shows similar increase in bilateral strength when training unilateral exercises contrary to those who only performed bilateral exercises (Mccurdy Langford, Doscher, Wiley, Mallard, 2005). This research also showed an increase in absolute and relative strength to subjects training unilateral exercises rather than bilateral exercises (Ibid). Regarding jumping performance, studies reports an increase in unilateral jumping height when training unilateral exercises rather than bilateral exercises which is kind of logic. But studies on volleyball players also shows an increase in bilateral jumping height when training unilateral exercises contrary bilateral exercises. This is interesting because that implies that all sports dominated with a jumping skill should be training unilateral exercises (Negrete & Brophy, 2000; Delcore, Mathieu, Salazar, Hernandez, 1998).

When performing resistance training athletes often carry out a number of sets at submaximal loads with several repetitions at a certain percentage of 1-RM and push to exhaustion. During these sets, fatigue is often experienced and is recognized as a multifactorial phenomenon often shown in loss of barbell velocity, the velocity drop is also a possible indicator for neuromuscular fatigue (Drinkwater, Pritchett, Behm, 2007; Sanchez-Medina and Gonzalez-Badillo, 2011). However no electromyographic muscle activity (EMG) was measured in this research, leaving a lack of knowledge surrounding the muscle patterning during these repetitions. In other studies on resistance training there is conflicting results regarding the muscle patterning. Some studies reports increased muscle activation during fatigue, some shows no changes in the muscle patterning and others reports a decrease of muscle activation. (Hakkinen, 1993; Lindstrom, Karlsson, Lexell, 2006; Walker, Davis, Avela, Hakkinen, 2012).

The hip abductors such as the gluteus medius and gluteus maximus is recruited to maintain alignment between the femur and pelvis in the sagittal, frontal, and transverse planes (Hollman, Ginos, Kozuchowski, Vaughn, Krause, Youdas, 2009) . Several studies with no external balance support and with use of electromyogram analysis shows a recruitment of the hip abductors in a single-leg stance (Ibid)(McCurdy et al,. 2006). Research from Leetun, Ireland, Willson, Ballantyne, Davis (2004) found that athletes with reduced activation of the hip abductors was most likely to get injured during the season (Willson, Ireland, Davis, 2006). Niemuth, Johnson, Myers, Thieman (2005) reported that runners with progressive overload injuries had reduced hip-abduction and external-rotation strength compared with healthy subjects. A weakness in the hip abductors or an imbalance between the hip abductors and the hip adductors is most likely to create an increased knee valgus which is related to different injuries such as patellofemoral pain syndrome (jumpers knee), iliotibial band syndrome (runners knee) and anterior cruciate ligament (ACL) injury (Hollman et al,. 2009). Research on one-legged squats in athletes supports this, reduced hip-external-rotation strength was correlated with increased knee valgus (Willson et al,. 2006).

The purpose of this study is to compare the differences in muscle activity and kinematic parameters between the unilateral squats and the bilateral squat in experienced resistance-trained subjects, performing one set of 4-RM for the bilateral squat and the same load as for one leg on the unilateral squats. Based on the shown literature, these hypotheses are brought forward a) you can achieve a higher power development in the unilateral squats contrary to the bilateral squat. b) Appearance of greater activation of the gluteus medius and gluteus maximus in the unilateral squats.

3. Methods

3.1 Experimental approach to the problem

Before the tests started the subjects were given a 2-week adaption period to learn the adequate technique with loads that approached their 4-RM for bilateral squat (90 degrees knee angle). Three exercises were used in this study: a) squat b) one-legged squat with barbell (foot forwards), c) one-legged squat with barbell (foot backwards). The procedure of the test started with finding the subjects 4-RM with bilateral squat then the total weight (bodyweight+ external weight) was divided to give similar resistance on the one-legged squat. This was done by taking the total weight of the bilateral squat divided by two. This was the resistance the subject needed to lift in the unilateral squats. The dependent variables were the time, velocity, and distance, together with the EMG activity of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semimembranosus, gastrocnemius, soleus, gluteus medius, gluteus maximus, oblique, erector spinae.

3.2 Subjects

Fourteen healthy male individuals with an average age, mass and height of 23 ± 4yr, 80,45 ± 8,52kg, and 1,81 ± 6cm participated in this study. Each had at least two years' experience of resistance training. The subjects did not perform any additional resistance training exercises targeting the lower extremities 72 hours before the test. Subjects without any history of neurological or orthopedic dysfunction, surgery or pain in the spine and lower extremities, were selected. All subjects signed written informed consent forms containing risk factors and their right to withdraw from the research at any time without stating a reason.

3.3 Exercise description

Bilateral Squat

The squat was performed on the force platform and the subjects were instructed to maintain the same feet position during the exercise. From this position, the subject with a barbell on the back flexed the knees and squatted down to a 90 degrees knee angle. In a continuous motion, the subject returned back to the starting position. To ensure an accurate knee angle, a line was set at the subjects’ 90 degree knee angle and he was required to touch this before he could return back to the starting position. The subject performed 4 repetition maximum (RM).

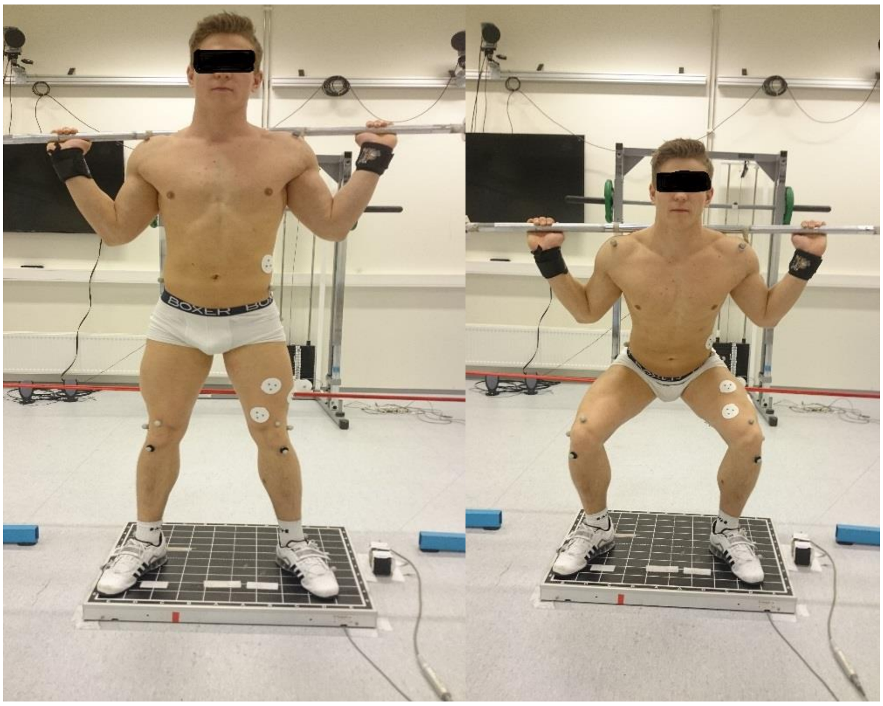


Figure.1: *Shows subjects starting position and lowest position in the bilateral squat.*

Unilateral squats

The unilateral squat was tested in two ways: with the foot backwards and forwards. The one-legged squat started with the subject standing with the preferred foot on the force platform. The knee of the preferred foot fully extended, the opposite knee bent approximately 90 degrees (foot backwards, fig.2) or fully extended but slightly elevated (foot forwards, fig.3) with a barbell on the back. From this position, the subject slowly flexed the knee of the preferred foot and squatted down to a 90 degrees knee angle. In a continuous motion, the subject returned back to the starting position. As in the bilateral squat a line was set at the subjects’ 90 degree knee angle and he was required to touch this before he could return back to starting position. A tape was used to ensure that the subject maintained the same foot position. The subject performed 4 repetitions with equal resistance on one leg as in the bilateral squat.

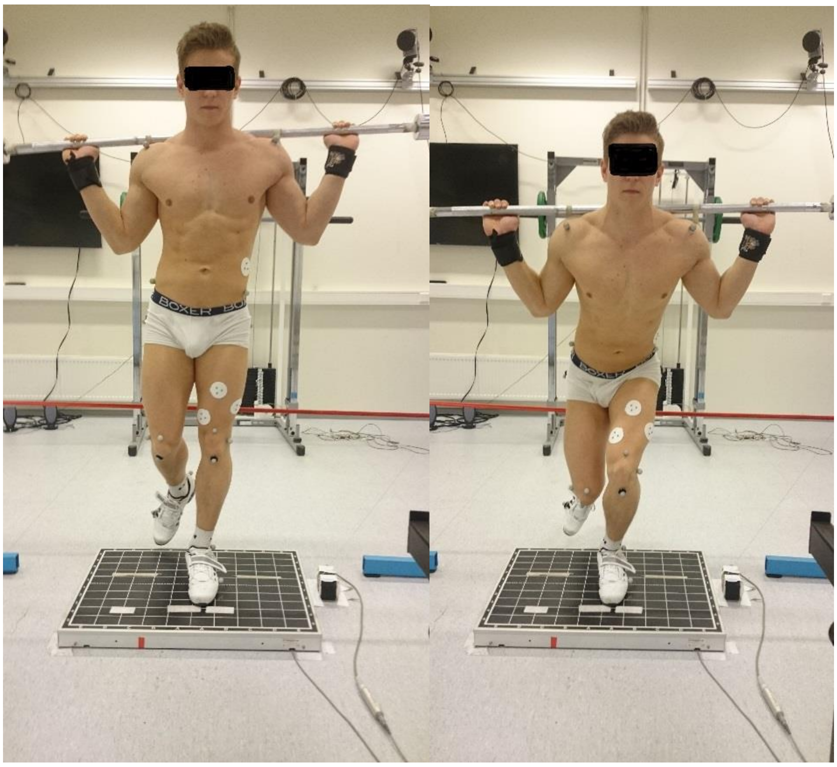


Figure.2: *Shows subjects starting position and lowest position in the unilateral squat foot backwards.*

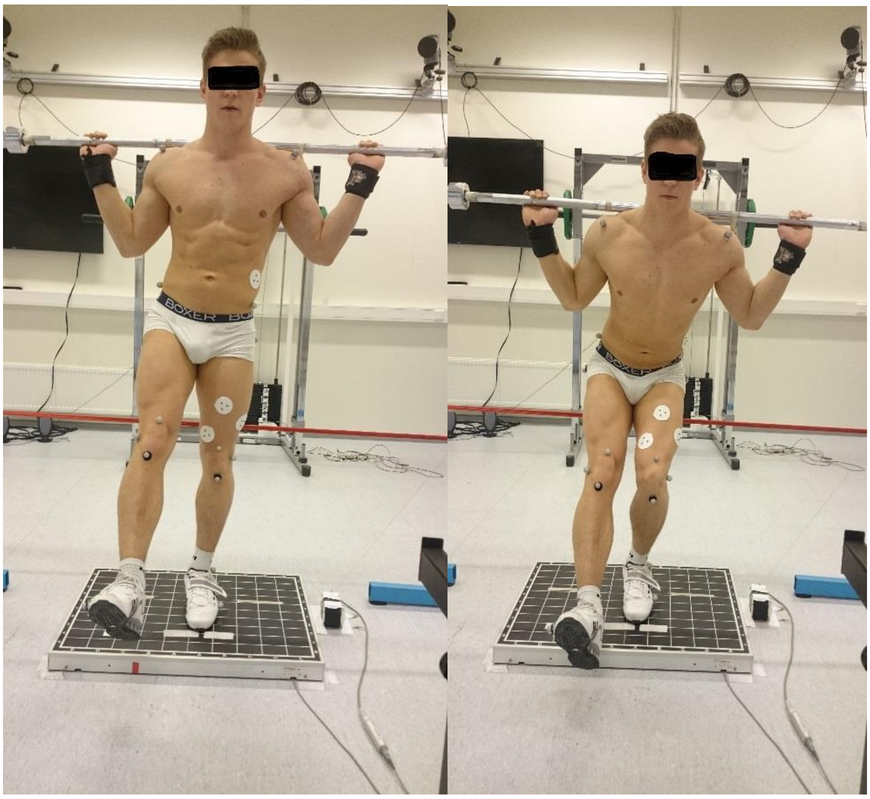


Figure.3: *Shows subjects starting position and lowest position in the unilateral squat foot forwards.*

3.4 Testing

Before the test started, the subjects were instructed to perform a 5-minute jog as a general warm up. Then a specific warm-up protocol was used, containing 4 warm-up sets a) 10 repetitions with no resistance than subjects own bodyweight, b) 10 repetitions with the barbell (20kg) c) 10 repetitions with 50% RM d) 6 repetitions with 70% RM. The percentage of RM was estimated based on the self-reported 1-RM of the participants. This warm-up procedure was used to prevent injury and ensure a better performance. At the attempt to reach 4-RM and between each exercise the subjects were given 5-minutes rest between each attempt to provide for an optimal performance (Rahimi, 2005). To ensure fatigue from one particular exercise did not afflict the data on another exercise, a randomized, controlled crossover study was used between one-legged squat foot forwards and one-legged squat foot backwards. Half of the fourteen subjects started with the one-legged squat foot forwards and the other half with the one-legged squat foot backwards.

Musclelab (MuscleLab 6000 system, Ergotest AS Porsgrund, Norway) with disposable surface electrodes (Dri-stick Silver circular sEMG Electrodes AE-131, NeuroDyne Medical, USA) were used to collect EMG data. As recommended by SENIAM, these oval shaped electrodes (11 mm contact diameter, 20 mm centre-to-centre distance) were placed in a bipolar electrode configuration along the longitudinal axis of each muscle with a center-to-center distance of 2.0 cm (Hermens Fredriks, Disselhorst, Rau, 2000). Before positioning the electrodes over each muscle, the skin was prepared by shaving, abrading, and cleaned with isopropyl alcohol to reduce skin impendence. The electrodes were placed on the subject´s dominant side. The muscles measured in this test were: a) vastus medialis, b) vastus lateralis, c) rectus femoris, d) gastrocnemius, e) gluteus maximus, f) gluteus medius, g) external abdominal oblique, h) erector spinae, i) semimembranosus j) biceps femoris. To minimize noise induced from external sources, the raw EMG signal was amplified and filtered using a preamplifier located as near to the pickup point as possible. The EMG signals were sampled at a rate of 1,000 Hz the signals were band pass filtered with a cut-off frequency of 8 and 600 Hz, after which the root mean square (RMS) was calculated. The RMS-converted signal was resampled at a rate of 100 Hz using a 16-bit A/D converter with a common mode rejection rate of 106 dB. The stored data were analyzed using commercial software (Musclelab V10.4, Ergotest Technology AS). To locate possible differences in muscle activity during the squat exercises, the average RMS was calculated for 2 regions in all repetitions. The first region was from the highest downward velocity to the lowest barbell point where the velocity is zero:

descending phase. The second region is from the lowest barbell point past the maximal barbell velocity until the velocity is zero: ascending phase.

A force plate (Ergotest Technology AS, Langesund, Norway) was used to record the ground reaction forces and the force moments in orthogonal directions. The signals were amplified, band-pass filtered and recorded. In addition to this a Linear Encoder (Ergotest Technology AS, Langesund, Norway) was connected to the barbell measuring the vertical position, lifting time and velocity during all 3 exercises with a 0.075-mm resolution and counted the pulses with 10 millisecond intervals (Arnason, Sigurdsson, Gudmundsson, Holme, Engebretsen, Bahr ,2004). The vertical displacement was measured in relation to the highest point of the barbell (zero distance). Velocity of the barbell was calculated by using a 5-point differential filter with software Musclelab V10.4 (Ergotest technology AS). The linear encoder was synchronized with the EMG recordings using a Musclelab 6000 and analyzed by software V10.4 (Ergotest Technology AS).

3.5 Statistical analysis

To assess the differences in neuromuscular activity in these two regions during the three squat exercises a repeated 3 (exercise: bilateral squat, one-legged squat foot forwards, one-legged squat foot backwards) x 4 (repetition) analysis of variance (two-way ANOVA) design on the descending and ascending part was used on the EMG data of the 11 muscles. On the kinematics (load, time, velocity and distance) a one-way ANOVA on the factor exercise with repeated-measures was used. The least significant difference in Holm-Bonferroni post hoc analyses was conducted to determine pairwise differences. All results are presented as mean ± SD. In case the sphericity assumption was violated, the Greenhouse-Geisser adjustments of the P values are reported. The level for significance was set at $P < 0.05$. Effect size was evaluated with η^2 (Eta partial squared) where $0.01<\eta^2<0.06$ constitutes a small effect, a medium effect when $0.06<\eta^2<0.14$ and a large effect when $\eta^2>0.14$ (Cohen, 1988). Statistical analyses were performed in SPSS version 21.0 (SPSS, inc., Chicago IL, USA).

4. Results

The 4-RM for bilateral squat was 134,82 ± 25,73kg, by dividing the total weight this gave an unilateral squat lifting weight at 27,89 ± 11,36kg. The lifting time (both descending as ascending) were significantly different in the three exercises ($F \geq 23,2$, $P<0,001$, $\eta^2 \geq 0,74$), but not for factor repetitions ($F \leq 1,6$, $P \geq 0,20$, $\eta^2 \leq 0,17$). Post hoc comparison showed that in both the descending part and the ascending part the lifting time was significant longer for the bilateral squat compared with the unilateral squats (P=0,001)(Fig.4). The ascending part also showed a significant longer lifting time for the unilateral squat with foot forward compared with the foot backwards (P=0,002)(Fig. 4).

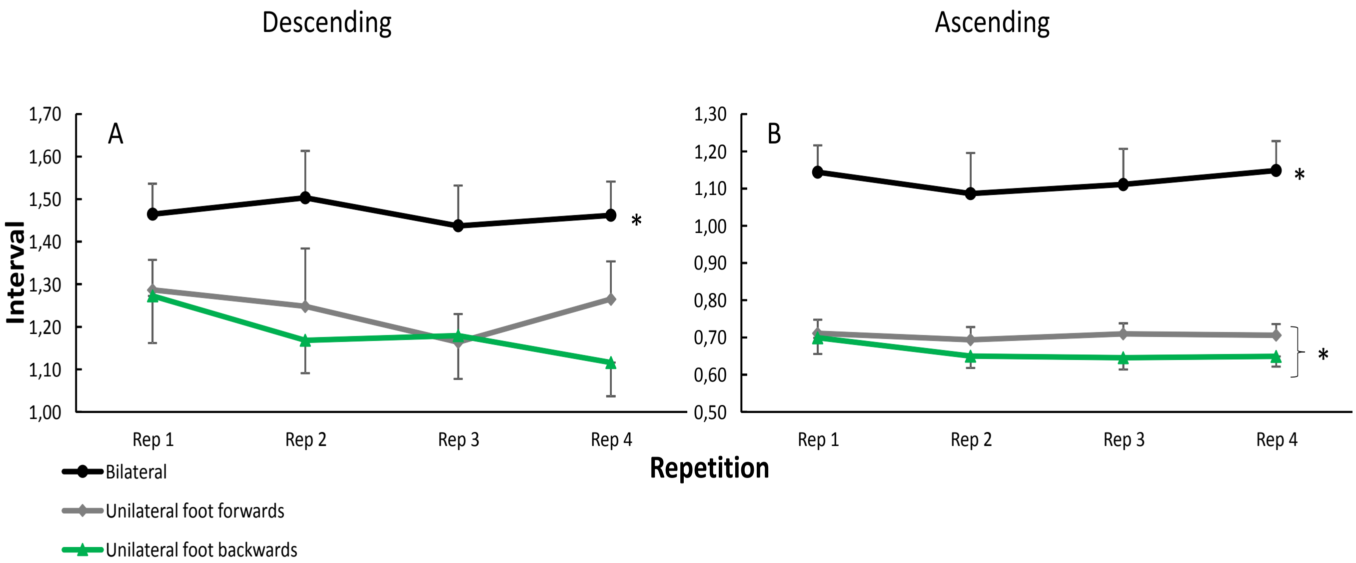


Figure. 4: *Mean (SD) Lifting time for each repetition of the a) descending and b) ascending part of the three different squats. *indicates a significant difference with all other exercises.*

The velocity (both descending as ascending) were significantly different among the three exercises and for factor repetition ($F \geq 3,3$, $P<0,045$ $\eta^2 \geq 0,32$). Post hoc comparisons showed that the maximal barbell velocity was significantly lower for the bilateral squat compared to both unilateral squats (Fig.5). In addition, the velocity increased for the factor repetitions for the unilateral squats from repetition 1-4 (P=0,005)(Fig.5).

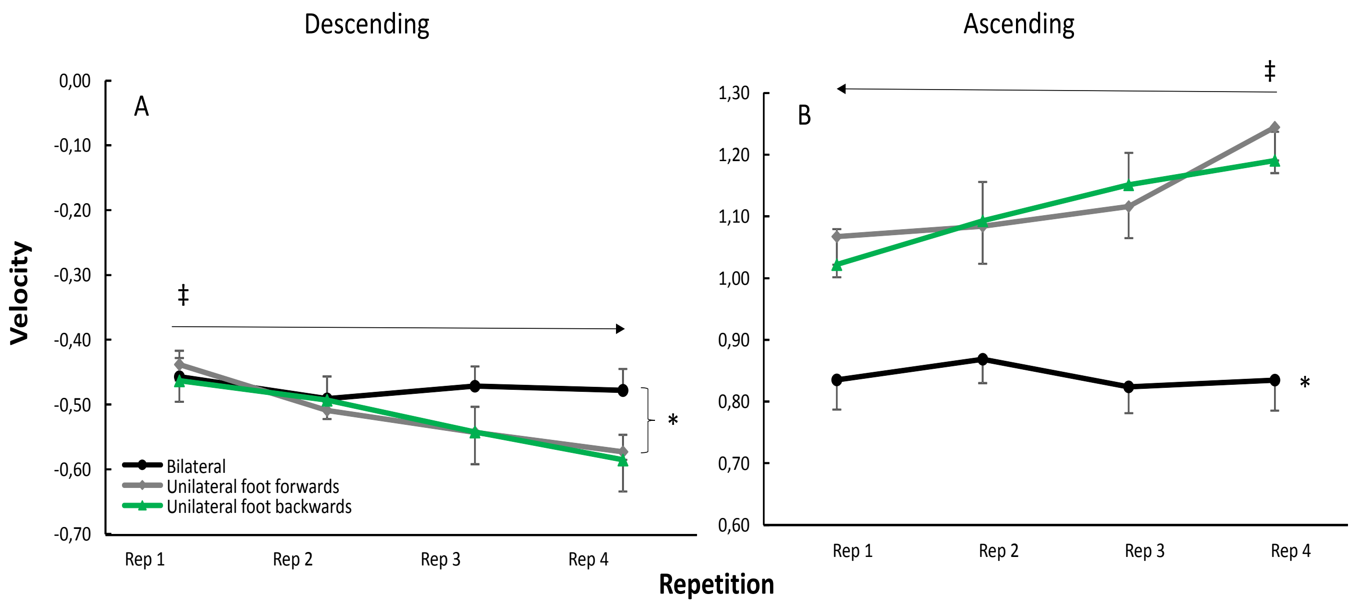


Figure.5: *Mean (SD) velocity for each repetition in a) descending phase b) ascending phase of the three different squats. * indicates a significant difference with all other exercises. ‡ indicates a significant difference between this repetition and all left/right from the sign.*

Among the three squat exercises there is a significant difference in the EMG activity in rectus femoris, vastus medialis and vastus lateralis in both descending and ascending phase ($F \geq 5,8$, $P<0,037$ $\eta^2 \geq 0,42$). A significant difference also occur for factor repetition in the ascending phase for rectus femoris and both descending and ascending phase for vastus medialis and vastus lateralis ($F \geq 3,4$, $P<0,034$ $\eta^2 \geq 0,33$). Post hoc comparison revealed that EMG activity was significantly higher for all three muscles between the bilateral squat and the unilateral squats in ascending phase for vastus lateralis and both phases for rectus femoris and vastus medialis ($P<0,013$)(Fig.6). In addition, results showed for the vastus medialis in the ascending phase a significantly higher activity in the unilateral squat foot forwards compared with the unilateral squat backwards ($P=0,004$)(Fig.6). In the descending phase there is a significant difference between the bilateral squat and the unilateral squat foot backwards ($P=0,017$)(Fig.6).

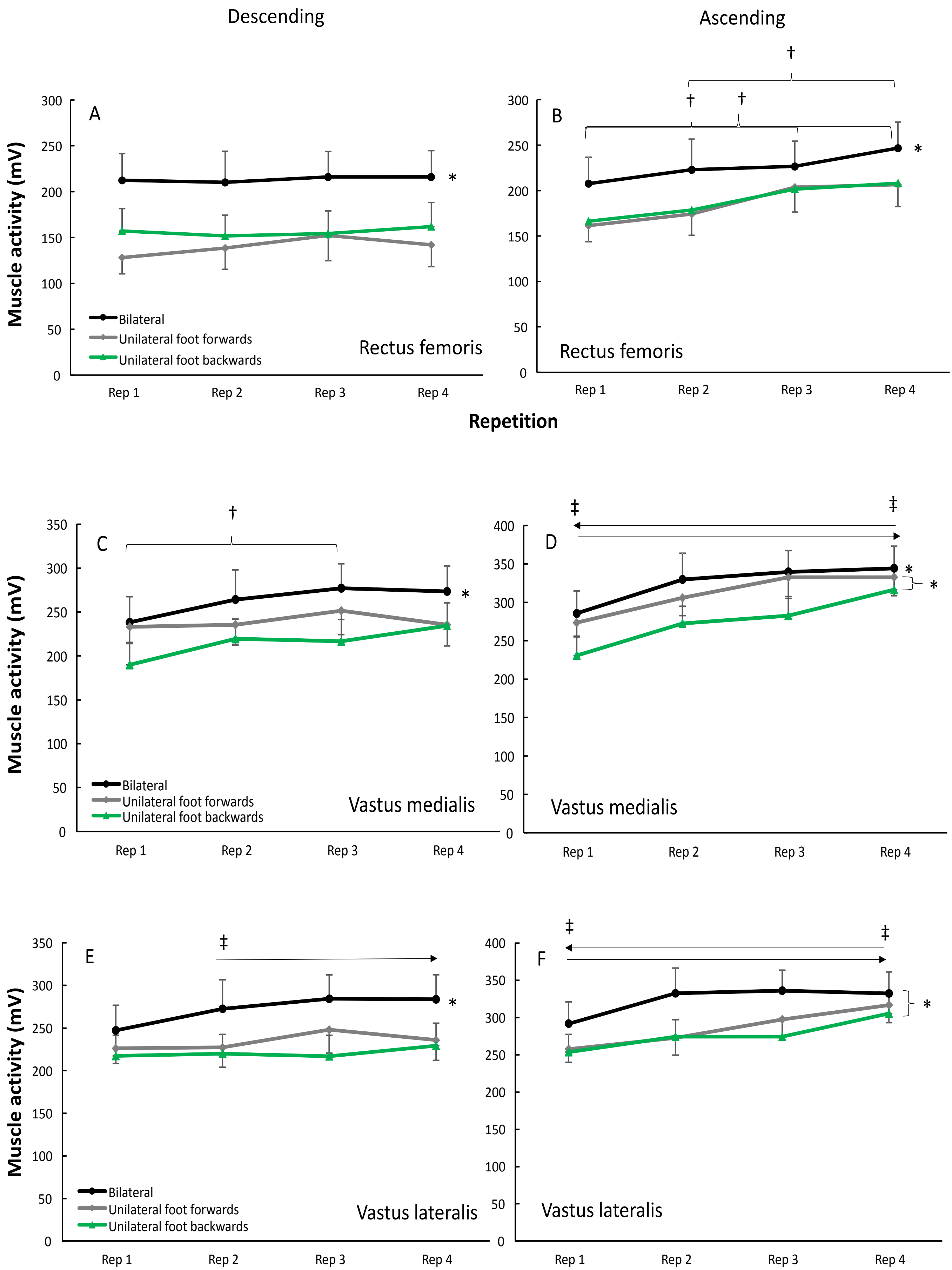
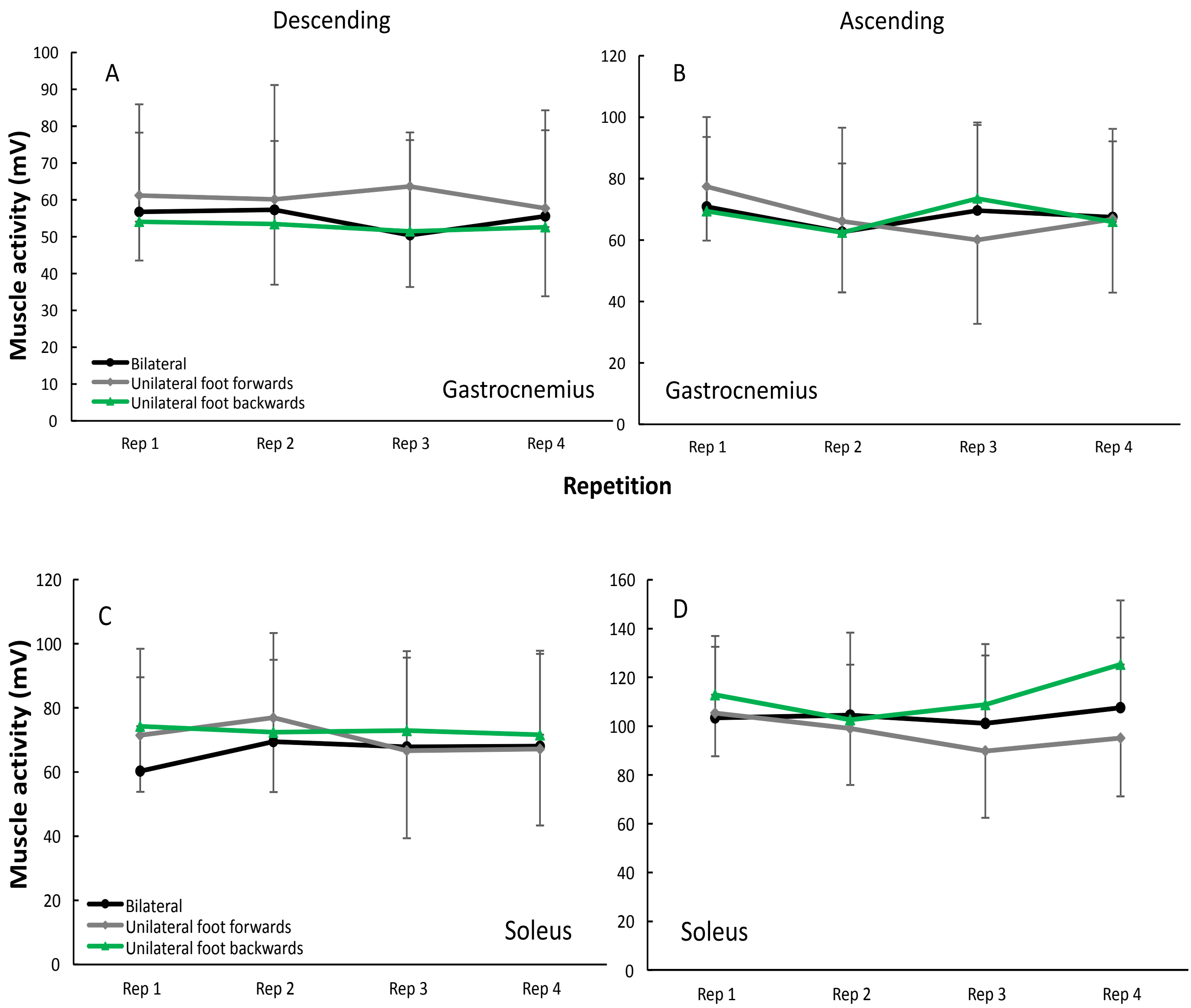


Figure.6: *Mean (SD) root mean square (RMS) EMG activity for each repetition of the rectus femoris, vastus*

*medialis and vastus lateralis in a) descending phase (rectus femoris) b) ascending phase (rectus femoris) c) descending phase (vastus medialis) d) ascending phase (vastus medialis) e) descending phase (vastus lateralis) f) ascending phase (vastus lateralis) of the three different squats. * indicates a significant difference with all other exercises. ‡ indicates a significant difference between this repetition and all left/right from the sign.*

No significant difference was found in the EMG activity on gastrocnemius, soleus, gluteus medius and gluteus maximus among the three squat exercises. For factor repetition no difference was found in descending phase for gastrocnemius, soleus and gluteus medius. In addition no difference was found in ascending phase for gastrocnemius, soleus and gluteus maximus ($F \leq 3{,}0$ $P \geq 0{,}077$ $\eta^2 \leq 0{,}20$). A significant difference was found in the ascending phase for gluteus medius and descending phase for gluteus maximus ($F \geq 6{,}2$ $P < 0{,}003$ $\eta^2 \geq 0{,}47$).



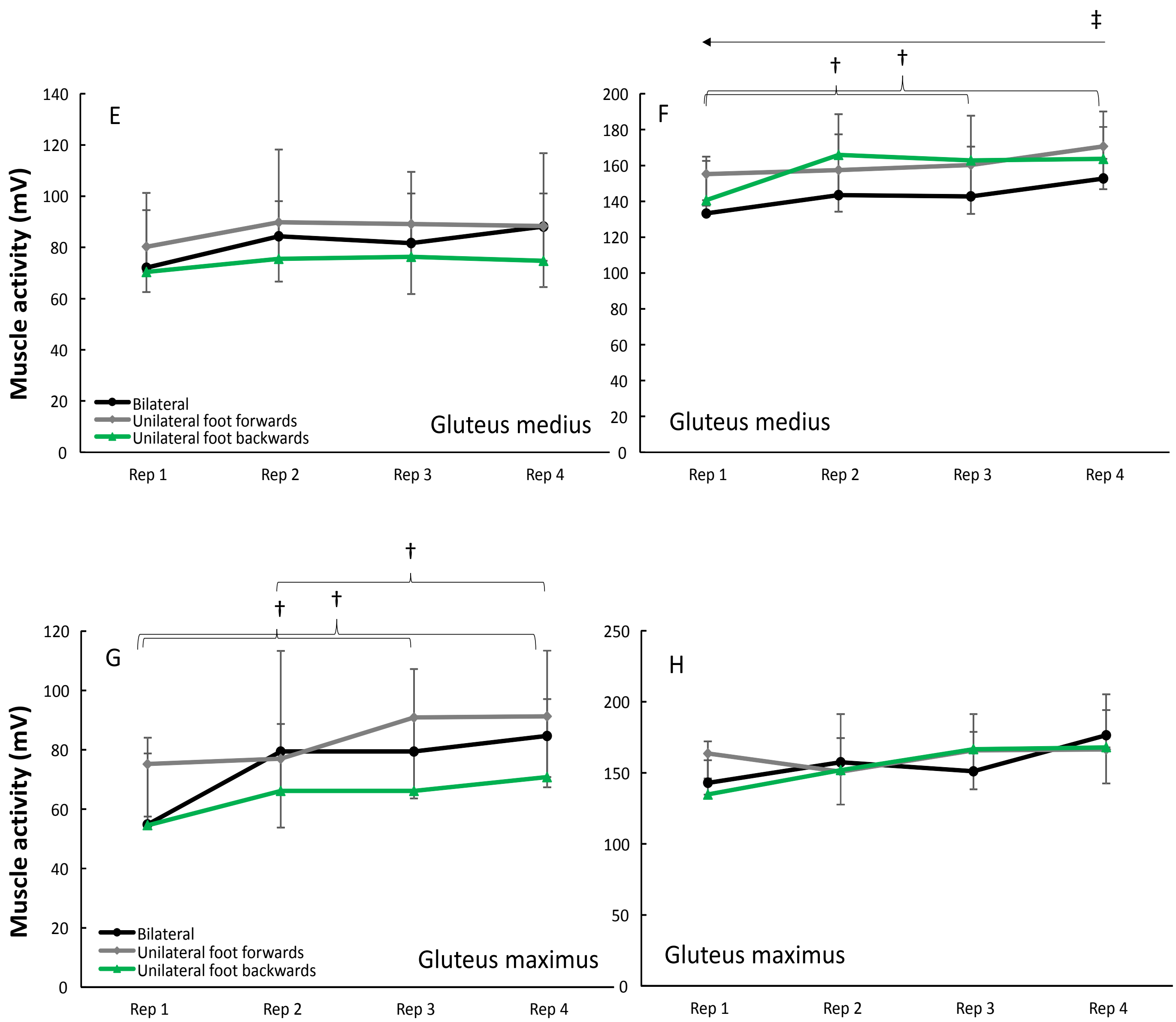


Figure.7: *Mean (SD) root mean square (RMS) electromyographic activity for each repetition of the gastrocnemius, soleus, gluteus medius and gluteus maximus in a) descending phase (gastrocnemius) b) ascending phase (gastrocnemius) c) descending phase (soleus) d) ascending phase (soleus) e) descending phase (gluteus medius) f) ascending phase (gluteus medius) g) descending phase (gluteus maximus) h) ascending phase (gluteus maximus) of the three different squats. † Indicates a significant difference between these two repetitions. ‡ indicates a significant difference between this repetition and all left from the sign.*

Regarding EMG activity on the biceps femoris no significant difference was found in the descending phase among the three squat exercises and for factor repetition (F≤2,3 P≥0,129 η^2≤0,25). But in the ascending phase there is a significant difference between the bilateral squat and the unilateral squats (P≤0,033)(Fig.8). In the ascending phase there is also a significant difference among the squat exercises and for factor repetition (F≥6,1 P≤0,018 η^2≥0,33). For the semimembranosus there is a significant difference among the exercises in the descending phase and for factor repetition in the ascending phase (F≥4,7 P≤0,026 η^2≥0,4). A significant difference was found between the unilateral squats in the descending phase (P=0,003)(Fig.8). No significant difference was found in the factor repetition in descending phase and among the squat exercises in ascending phase (F≤2,3 P≥0,098 η^2≤0,25).

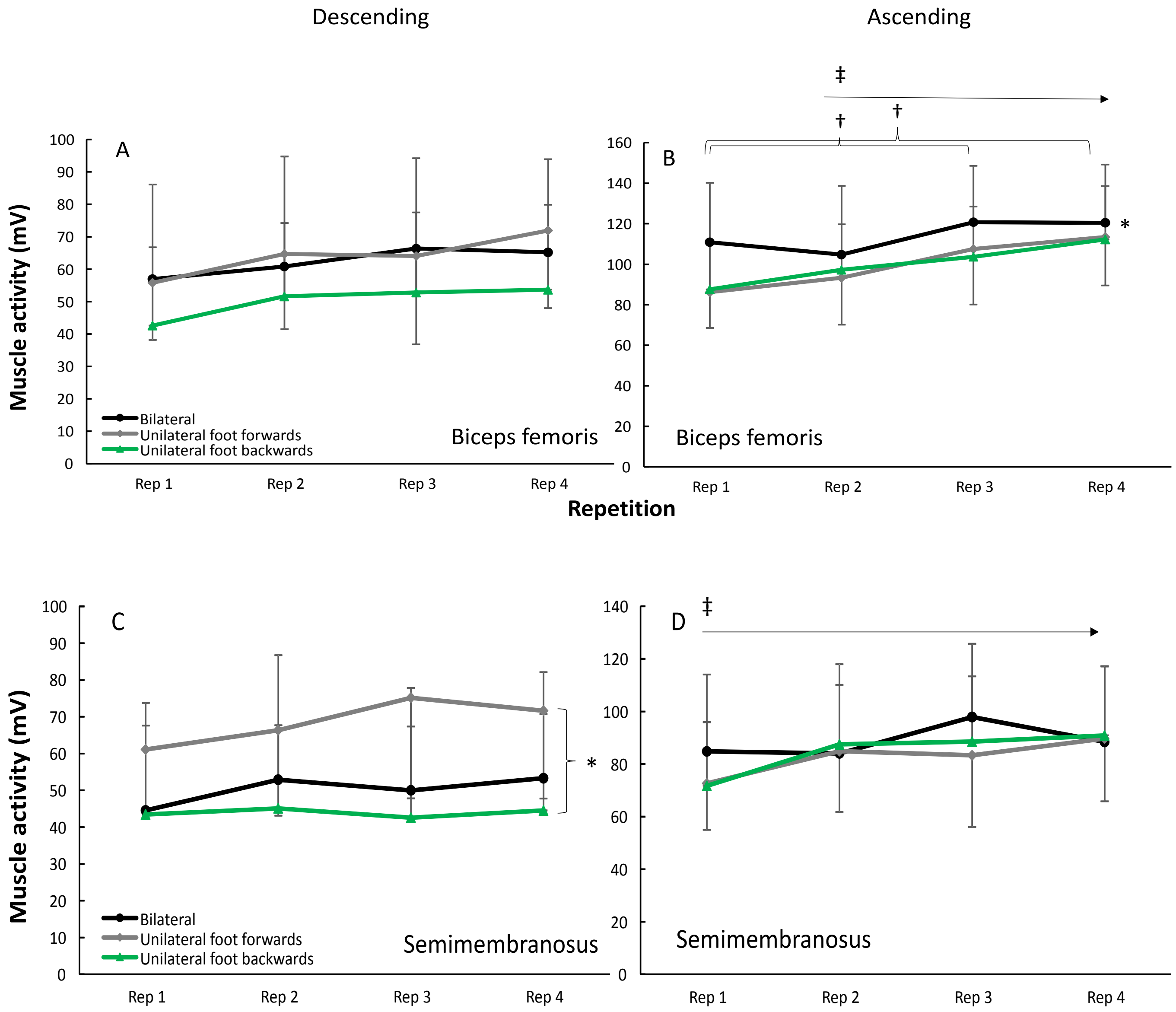


Figure.8: *Mean (SD) root mean square (RMS) electromyographic activity for each repetition of the biceps femoris and semimembranosus in a) descending phase (biceps femoris) b) ascending phase (biceps femoris) c) descending phase (semimembranosus) d) ascending phase (semimembranosus) of the three different squats. * indicates a significant difference with all other exercises. † Indicates a significant difference between these two repetitions. ‡ indicates a significant difference between this repetition and all right from the sign.*

For the oblique there is no significant difference among the three exercises and between the repetitions in both descending and ascending phase (F≤3,1 P≥0,084 $\eta^2 \leq 0{,}20$). For the erector spinae there is a significant difference among the three squat exercises in the descending phase and for factor repetition in the ascending phase (F≥5,2 P≤0,012 $\eta^2 \geq 0{,}30$). It's a significant difference between the unilateral squats and also between the unilateral squats and the bilateral squat (P≤0,022)(Fig.9), There is no significant difference in the factor repetition in the descending phase and between the exercises in the ascending phase (F≤1,2 P≥0,284 $\eta^2 \leq 0{,}09$).

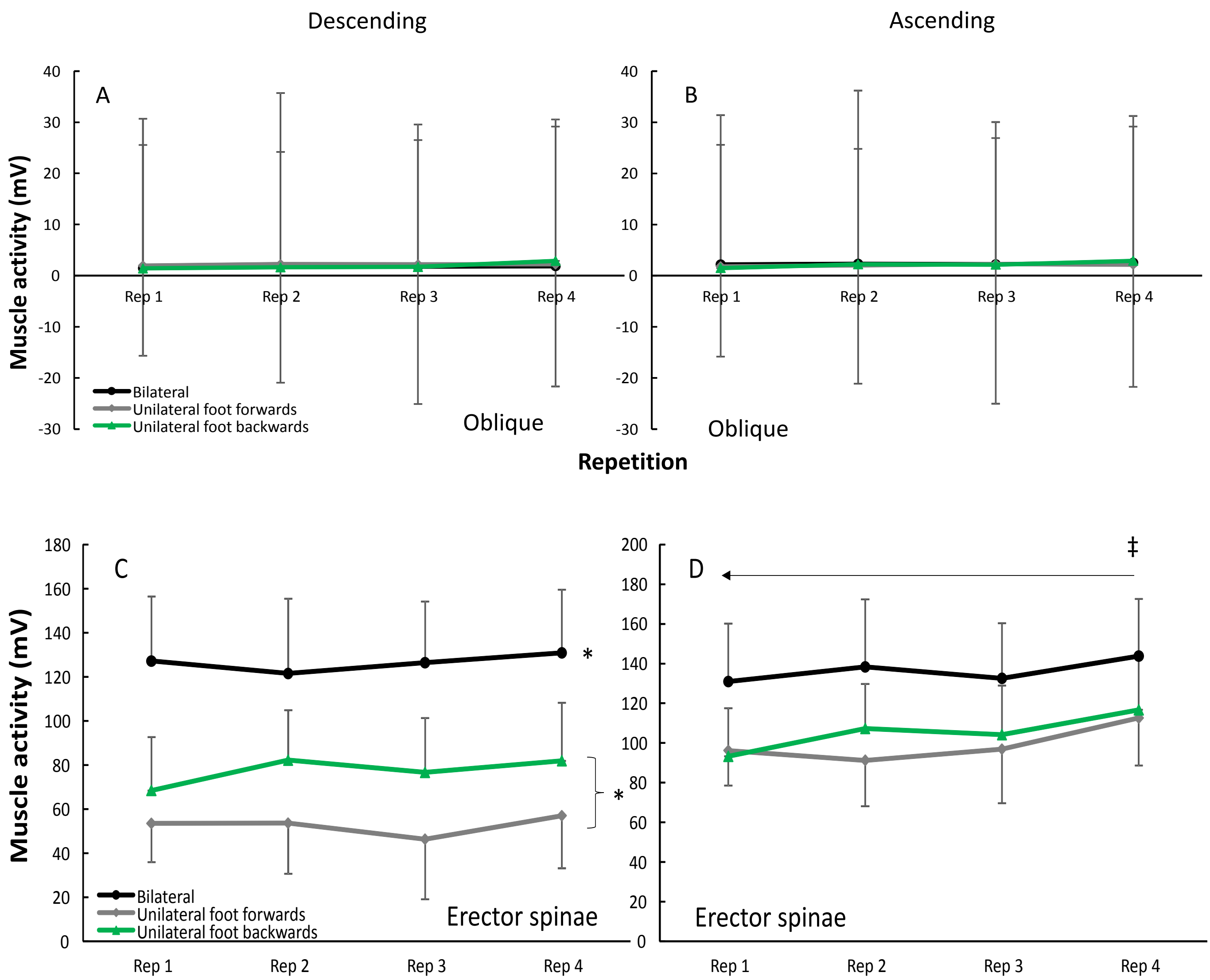


Figure.9: *Mean (SD) root mean square (RMS) electromyographic activity for each repetition of the external abdominal oblique and erector spinae in a) descending phase (oblique) b) ascending phase (oblique) c) descending phase (erector spinae) d) ascending phase (erector spinae) of the three different squats. * indicates a significant difference with all other exercises. ‡ indicates a significant difference between this repetition and all left from the sign.*

5. Discussion

The purpose of this study was to compare the differences in muscle activity and kinematic parameters between the unilateral squats and the bilateral squat. The main findings were a lower barbell velocity and a longer lifting time for the bilateral squat compared to the unilateral squats. For the unilateral squats an increase of velocity in factor repetition. Results showed a higher activation of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris and erector spinae in the bilateral squat compared to the unilateral squats. For the unilateral squat foot forward, a higher activation was found for the semimembranosus and vastus medialis and a lower activation of the erector spinae. This in the comparison to the unilateral squat foot backwards. In addition to this the results show an increase in the measured EMG from repetition 1 to repetition 4 for both unilateral squats and the bilateral squat.

As hypothesized the total lifting time was longer and the barbell velocity was lower for the bilateral squat compared to the unilateral squats. In addition to this the velocity increased from repetition 1-4 for the unilateral squats which indicates that no fatigue occurred in the unilateral squats and also that the power development was higher in the unilateral squats because F= M x A (Force equals mass times acceleration)(Drinkwater et al., 2007; Sanchez-Medina and Gonzalez-Badillo, 2011). These findings supports the theory of bilateral force deficit because the mechanical output per leg is less in two-legs than in one-leg based on the equation (F= M x A) (Baechle & Earle, 2000; Bobbert et al,. 2006). Furthermore, it is possible that some of the progressive increase in barbell velocity is due to a slight familiarization of the movement pattern and the balance aspect during the unilateral squats.

In the measured EMG for the rectus femoris, vastus medialis and vastus lateralis there is a significant higher activation in the bilateral squat compared to the unilateral squats except for vastus lateralis in the unilateral squat foot forward (ascending phase). The reason why there is a higher activation of the quadriceps comparing the bilateral squat and unilateral squats is probably due to a higher barbell load. This create a gravitation force that demands a higher activation of the quadriceps to prevent the subject from falling backwards. Even though the load was divided to have equal resistance among the exercises the load is still more spread in the unilateral squats compared to the bilateral squat where most of the load is on the back. In addition the unilateral squat foot forward had a higher activation of the vastus medialis compared to the unilateral squat foot backward (Fig.6). This is probably due the differences in movement pattern. The unilateral squat foot backwards allows you to have a more forward tilt on the upper body, which moves the center of gravity where less activation of the vastus medialis is needed. In the activation of the gastrocnemius, soleus and the oblique there is no significant difference in the bilateral squat compared to the unilateral squats. The movement pattern in these exercises does not significantly challenge these muscles in a different way (Fig. 7,9). Contrary to hypothesis b), the results shows no significant difference among the exercises (Fig.7). The belief in a higher activation in the unilateral squats is because the role the muscles play in stabilizing the upper body in a unilateral stance, in addition the gluteus medius also plays an important part in abducting the femur (Neumann & Cook, 1985; McCurdy et al,. 2006; Hollman et al,. 2009). There are several possible explanations why the hypothesized difference did not occur. Firstly, weakness in the hip abductors. Assessing the subjects individually, it was clear that some had a greater activation of the gluteus medius and gluteus maximus in the unilateral squats. The hip abductors plays an important part of preventing knee valgus, but if there is a weakness in the abductors or an imbalance between the abductors and the adductors, this may create an increased knee valgus and an unfavorable position for activation of the gluteus medius and gluteus maximus. Secondly, the bilateral squat allows the subjects to use a wider stance which is a more favorable position for activation of the hip abductors. Because of these aspects there would be interesting to analyze the continuous motion of these three squat exercises in a 3D-optical system.

Results show a higher activation of the biceps femoris in the bilateral squat compared to the unilateral squats (ascending phase)(Fig.8). Probably for the same reason as for the gluteus medius and gluteus maximus regarding that the bilateral squat allows the subject to use a wider stance (Fig.1-3). The biceps femoris is also a hip abductor, the wider stance and a bigger support surface makes it easier to abduct the knees which gives a greater activation of the biceps femoris. For the unilateral squat foot forward a higher activation was found in the descending phase of semimembranosus. This is probably due to the difference from the other exercises, where the movement starts from the hip. This exercise’s initial movement is to flex the knee which provide for a greater activation of the semimembranosus. Results for the EMG measured on erector spinae showed a significant higher activation in the bilateral squat compared to the unilateral squats. The reason this occur is due to the higher barbell load which create a higher tension on the spine and the surrounding muscles such as the erector spinae. In addition there is a pattern of increased measured EMG from repetition 1 to 4 which indicates no neuromuscular fatigue when performing 4-RM bilateral squat and for the unilateral squats.

There are some limitations in the study. Firstly, Surface EMG can only provide an estimate of the neuromuscular activation, and there is a risk of crosstalk from neighboring muscles, even if a small inter-electrode distance was used (Farina, 2006). Secondly, a 3D-dimensjon optical system was used but not analyzed due to time limitations. An analyzis of the angles and the movement pattern would give more accurate answers for the difference in the muscle activation and kinematic parameters. Thirdly, an adaptation period was given to learn proper technique in the unilateral squats but the bilateral squat was a more familiar exercise. Due to this there is a possibility that the balance aspect may have had an influence on the unilateral squats.

6. Conclusion

The results of kinematic parameters demonstrated an important practical application for strength training. Increased velocity for the unilateral squats in comparison with the bilateral squat indicates a greater power development (F=M x A). The results of this study shows that the bilateral squat, compared to the unilateral squats, is more likely to be the most effective exercise for strengthening of the quadriceps, biceps femoris and erector spinae. The unilateral squat foot forward is most likely the best exercise for strengthening of the semimembranosus. Data from the measured EMG for erector spinae demonstrated a practical application for strength training as it show significantly lower activity in the unilateral exercises. Thus making it able to do squat exercises with equal resistance as 4-RM bilateral squat, but with less pressure on the back.

Future research should measure the differences in muscle activity and kinematic parameters in 4-RM bilateral squat contrary to 4-RM unilateral squat.

7. References

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