EFFECT OF ANKLE MOBILITY AND SEGMENT RATIOS ON TRUNK LEAN IN THE BARBELL BACK SQUAT

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ABSTRACT

Fuglsang, EI, Telling, AS, and Sørensen, H. Effect of ankle mobility and segment ratios on trunk lean in the barbell back squat. *J Strength Cond Res* 31(11): 3024–3033, 2017—The barbell back squat is a popular exercise used for both performance enhancing and rehabilitation purposes. However, injuries are common, and people with a history of lower back pain are especially vulnerable. Past studies have shown that higher trunk angles (less forward lean) generate less stress on the lower back; thus, it seems appropriate to investigate the factors presumed to influence the trunk angle. Therefore, the aim of this study was to investigate how ankle mobility and the segment ratios between the thoracic spine, thighs, and shanks influence the trunk angle in the back squat. While recorded with motion capture, 11 male subjects performed 3 repetitions at approximately 75% of 1 repetition maximum in the squat to a parallel position (thighs horizontal) or lower. Furthermore, subjects performed a weight bearing lunge test to determine maximal range of motion (ROM) of the ankle joint. Segment angles of the shank, thigh, and trunk segments as well as ankle joint angles were calculated by 2-dimensional kinematic analysis. Simple linear and multiple regressions were used to test the correlation between the lower extremity angles, segment ratios, and the trunk angle. On average, subjects had an 11.4 ± 4.4° deficit in dorsiflexion ROM between maximal ROM and ROM in the parallel squat (PS) which was independent of maximal ROM. Ankle mobility showed to significantly negatively correlate with trunk angle, thereby showing that a subject with greater ankle ROM had a more upright torso in the PS position. This study was unable to find a significant correlation between the segment ratios and trunk angle. Furthermore, when combined, no significant relationship between ankle mobility, segment length ratios, and trunk angle were found, although it was noticed that this more complex model showed the greatest R^2 value.

KEY WORDS dorsiflexion, parallel squat, kinematics, ROM, weight bearing lunge test, motion capture

INTRODUCTION

The parallel squat (PS), i.e., anterior thighs horizontal in the lowest position, is known to be a great exercise for improving lower-body strength and sports performance through better vertical jump and sprint ability (4,15). Also, it has been shown to be a great rehabilitation exercise for different knee injuries such as anterior cruciate ligament deficiencies and patellofemoral syndrome (25).

The squat is a closed kinetic chain exercise (32). By this fact, the horizontal position of the bar and the center of gravity will always have to be balanced over the midfoot to maintain balance (6,29). All joint/segment angles must then be coordinated to ensure a movement pattern that keeps the bar in this position throughout the entire movement. Hence, some amount of trunk lean must occur if the hip moves backward during the decent of the back squat. This point serves as the primary argument for how individual variables such as ankle dorsiflexion range of motion (DF-ROM) and segment length ratios can influence the kinematics of the squat. This is in accordance with the findings in the literature showing that anthropometrics and ranges of motion are among the most important variables affecting the execution of the barbell back squat (2,8,21,24). The most common injuries caused by weight training are injuries to the lower and upper trunk (18).

In a position statement published by the National Strength & Conditioning Association (NSCA), poor squatting technique is proposed to increase the risk of injuries to the lower back (3). To prevent injuries, the NSCA recommends that the athletes maintain a normal lordotic posture with the torso as close to vertical as possible during the entire lift. Thus, it is interesting to examine which biomechanical factors are influencing trunk lean.

McKean et al. (2012) examined how segment lengths and segment ratios influence the hip, knee, and ankle coordination during the squat. In the study, height and torso length correlated negatively with the maximum anterior hip angle. Taller men tended to squat with a lower anterior angle between the thighs and the trunk. This lower angle was achieved by either more forward trunk lean or a deeper squat (22).

A recent study by Sato et al. (30) showed that weightlifting shoes (with elevated heels) could minimize forward trunk lean. This was due to the weightlifting shoes providing

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TABLE 1. Variables measured in the tests.

Variable	Mean ± *SD*
Shank length (cm)	44 ± 1.9
Thigh length (cm)	41.5 ± 1.9
Trunk length (cm)	59.1 ± 2.3
Shank/thigh ratio	1.063 ± 0.055
Trunk/shank ratio	1.344 ± 0.07
Trunk/thigh ratio	1.427 ± 0.089
Shank angle WBLT (°)	47.8 ± 5.7
Shank angle in parallel squat (°)	59.2 ± 4.8
Trunk lean in parallel squat (°)	56.9 ± 5.4

WBLT = weight bearing lunge test.

artificial forward knee movement, which is similar to increased ankle dorsiflexion (DF). Thereby, the shear forces in the lumbar region can be reduced during the PS with weightlifting shoes as opposed to squatting barefooted or in running shoes (10,31). By the fact that weightlifting shoes minimize trunk lean, it can be hypothesized that a lower angle between the shank and horizontal (measured anteriorly) allows the trunk to stay more upright in the squat (2).

If trunk lean is correlated to back injuries, it is necessary to determine which variables influence trunk lean. On the basis of former studies, it makes sense to examine whether ankle mobility and anthropometrics influence the degree of forward trunk lean during the squat. Trainers could use this information to prevent development of lower back pain in athletes or optimizing performance (3). Hence, the purpose of this study was to investigate how mobility of the ankle (DF-ROM) and segment ratios between the thoracic spine, the thighs, and the shanks influence the trunk angle during the PS. Furthermore, it was examined whether use of ankle mobility in the PS is limited by maximal ankle ROM, a natural deficit in DF usage within the PS or is individually dependent. This information could be used to determine whether improving ankle mobility could have a beneficial effect on minimizing trunk lean.

It was hypothesized that a lower anterior angle between the shank and horizontal (greater maximal DF-ROM) would result in a more upright trunk in the squat, and that a greater shank/thigh and trunk/thigh ratio would lead to a more upright trunk.

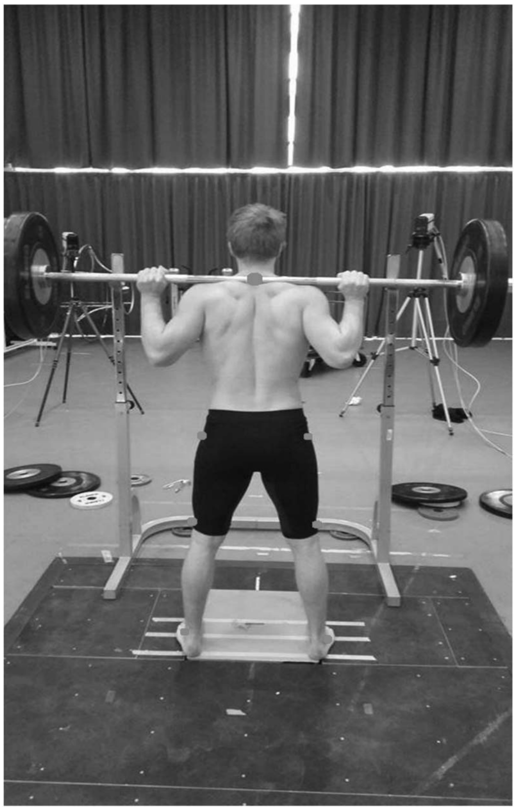

Figure 1. Experimental set-up showing the placement of the markers (red) and the weightlifting bar.

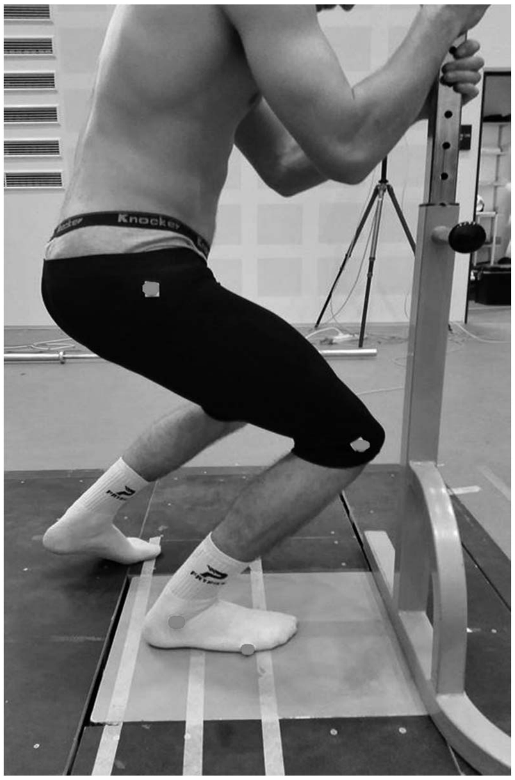

Figure 2. Lunge test viewed from the sagittal plane. 3D-markers placements highlighted with red.

METHODS

Experimental Approach to the Problem

A cross-sectional design was used to examine the kinematics of the PS and the maximum ankle DF-ROM in a weight bearing lunge test (WBLT) for each subject. The results from the WBLT were used as a reference point for the PS, so a deficit in use of ankle DF could be calculated. In addition, it was tested if the WBLT (independent variable) correlated with ankle DF in the PS (dependent variable). Second, the kinematics of the squat and the anthropometric data of the subjects were used to develop simple linear and multiple regressions to test for correlation between segment ratios (independent variable), ankle mobility (independent variable), and trunk angle in the PS (dependent variable). Results from the regressions established whether or not the WBLT was a suitable test for use of ankle DF in the PS and also whether differences in ankle mobility and segment lengths correlated with trunk angle. Furthermore, the results from the regressions

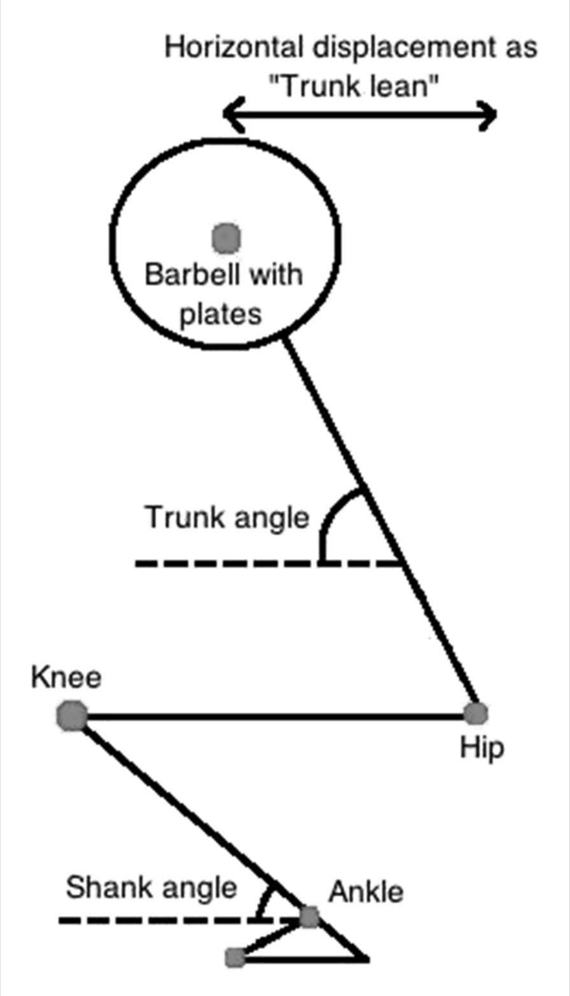

Figure 3. Kinematic model of the parallel position of the squat.

TABLE 2. Results of the 4 regression models.*

Dependent variable	Model	Independent variable	R^2	Adjusted R^2	T	Intercept	B	*SE*	*p* independent variables	*p* model
Shank angle WBLT (°)	Model 1	Shank angle in parallel squat	0.41	0.35	2.50	3.39	0.75	0.30	0.034	0.034†
Trunk angle (°)	Model 2	Shank angle WBLT	0.45	0.39	−2.71	87.75	−0.64	0.24	0.024	0.024†
Trunk angle (°)	Model 3	Segment ratios	0.37	0.10		1,088.60				0.334
		Trunk/thigh			1.61		683.30	424.90	0.152	
		Trunk/shank			−1.62		−734.10	453.10	0.148	
		Shank/thigh			−1.67		−960.10	574.50	0.139	
Trunk angle (°)	Model 4	Shank angle WBLT	0.60	0.33	−1.85	753.80	−0.67	0.36	0.113	0.183
		Segment ratios								
		Trunk/thigh			1.27		483.94	381.49	0.252	
		Trunk/shank			−1.22		−500.40	409.28	0.267	
		Shank/thigh			−1.23		−642.64	523.66	0.266	

*WBLT = weight bearing lunge test.
†$p \leq 0.05$.

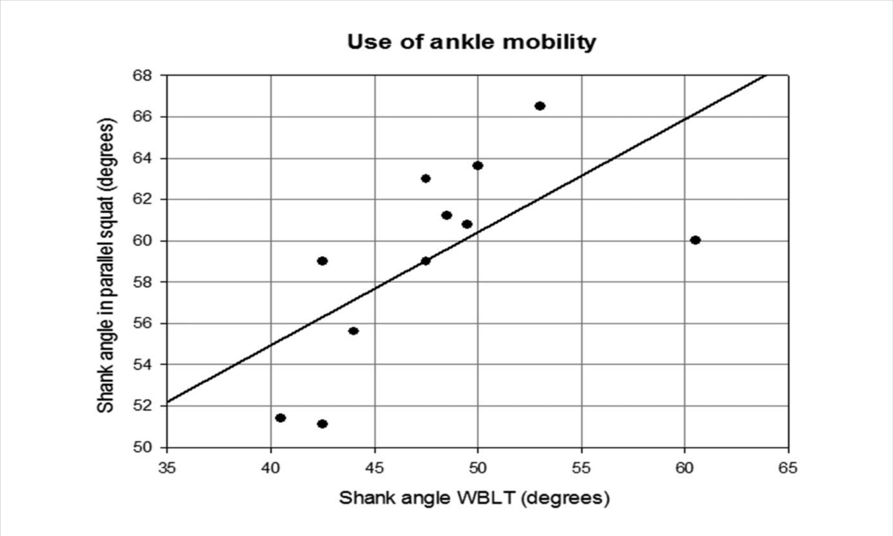

Figure 4. Simple linear regression between shank angle in the weight bearing lunge test and shank angle in the parallel squat.

showed whether variables correlated positively or negatively with trunk angle, thereby explaining the influence of segment lengths and ankle mobility on trunk lean.

Subjects

Fourteen male athletes were recruited from Department of Sport Science at Aarhus University (age: 22.9 ± 1.8 years, range: 19–26 years, height: 1.80 ± 0.04 m, weight: 78.4 ± 4.7 kg.). Fourteen subjects participated in the study; however, 3 were excluded because of being unable to reach a PS position, given the restrictions set for the test. All subjects were recreational athletes familiar with heavy weight training, including back squat and had on average 4.1 years (range: 1.5–8) of experience with a minimum 2 training sessions per week. Furthermore, the subjects had not been injured 6 months before testing. Anthropometric data for the subjects are presented in Table 1. Written informed consent to participate in the study was obtained from all subjects after receiving detailed information about the measurement procedures. The project was approved by the local ethics committee, and participants were questioned for any health risks of concern.

Instrumentation

Eight Qualisys ProReflex MCU 1,000 cameras (Qualisys, AB, Gothenburg, Sweden) placed in a circle around the test site were used for motion capturing. Position data were captured at 240 frames per second using Qualisys Track Manager v.2.9. Reflective markers were placed bilaterally on the subjects at the following sites: trochanter major (hip), epicondylus lateralis (knee), malleolus lateralis (ankle), caput metatarsalis V (toe); and one was placed at the center of the bar (Figure 1). Segment lengths were found as the distance between these markers in the sagittal plane in upright position of the squat. Slight movements in the frontal plane might have influenced the results; however, these movements are considered to be minor, and approximately the same for all subjects. The length of the shank was measured as the distance between the reflective markers on epicondylus lateralis and

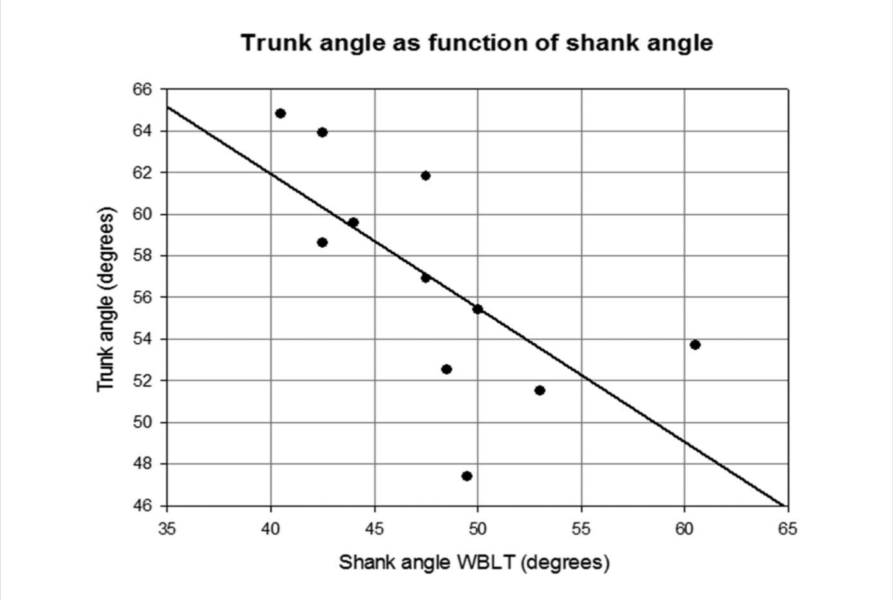

Figure 5. Simple linear regression between shank angle in the weight bearing lunge test and the trunk angle in the parallel squat.

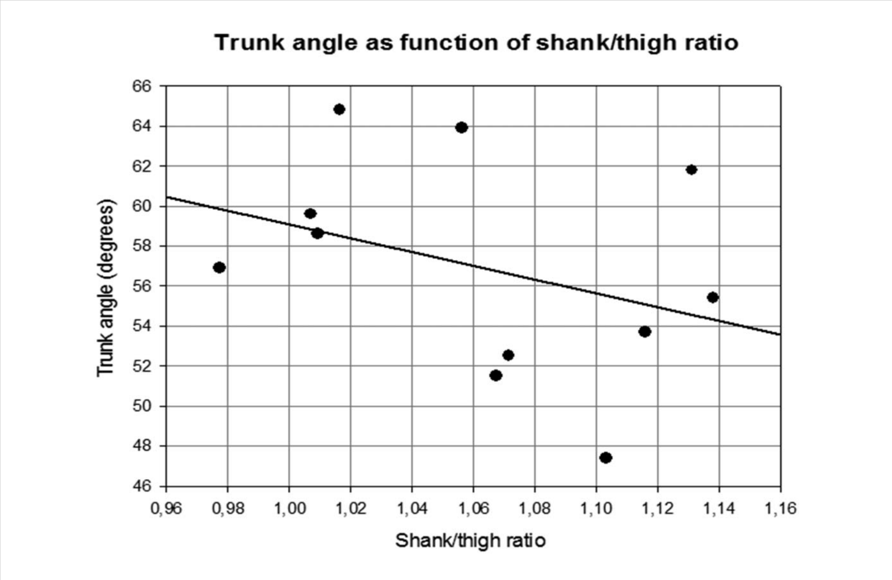

Figure 6. Simple linear regression between shank/thigh ratio and trunk angle in the parallel squat.

malleolus lateralis. The length of the thigh was measured as the distance between trochanter major and epicondylus lateralis. The length of the trunk was measured as the distance between the average position of the reflective markers on the 2 trochanter majors and the marker at the center of the bar. For all subjects, the bar was placed just under cervical vertebra 7, i.e., they all did high bar squat (36). SigmaPlot 12.0 was used for position analyzes and visual presentation. Simple linear regressions, multiple regressions, and data analyzes were computed in the statistical software R v.3.2. For the squat, an Eleiko weightlifting bar (20 kg) and Eleiko bumper plates were used. For warm-up, a Monark 818e Ergomedic Fitness Bike was available for use.

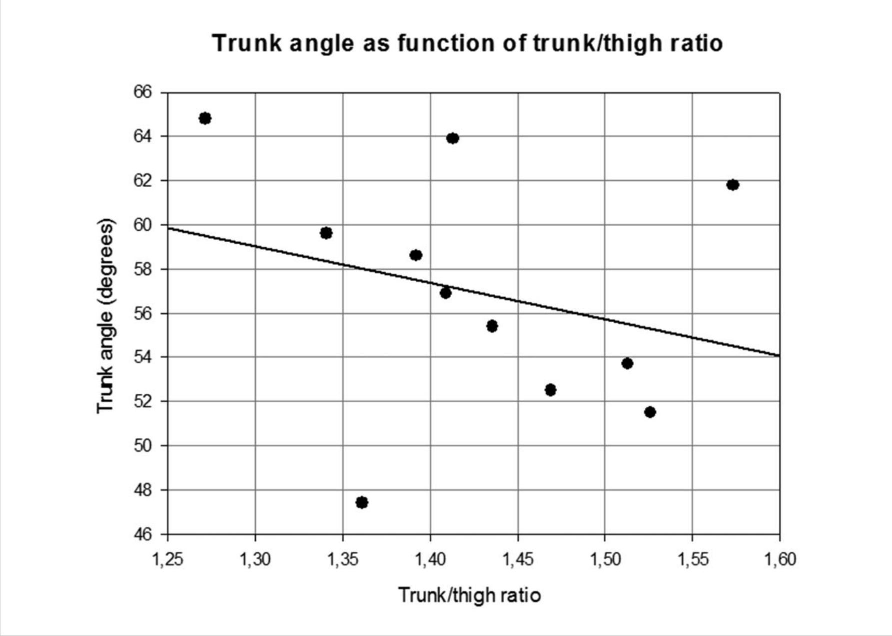

Figure 7. Simple linear regression between trunk/shank ratio and trunk angle in the parallel squat position.

Procedures

Data collection was completed during the spring and throughout the day at the time that suited the subjects best. Time of testing was not controlled; however, all subjects were tested between 10 AM and 2 PM. All subjects were asked not to work out before or at the day of testing. On arrival, subject's height, weight, and distance between acromions were measured. All subjects were asked for their self-estimated 1 repetition maximum (1RM) (estimated 1RM: 136.8 ± 24.4 kg.) for the barbell back squat and asked to perform the test with approximately 80% of their max for 3 reps (performed lift: 102.7 ± 22 kg, percentage of 1RM: 75%). This was to ensure that the weight used in the study simulated a standard weight used for strength development in trained athletes (27). The distance between acromions was used to determine the stance width for subjects in the squat. As in most studies on squat, the stance width would then be shoulder width and varied according to subjects' heights (5,13,21,30,35). This was due to a study showing that a wide stance squat requires less DF than a narrow stance squat (9). The stance width was marked on the floor with tape for placement of the feet during the squat. All subjects were instructed not to use shoes for the test. This was to ensure no inclining effects from footwear on the results.

The test started with the subjects performing an individually preferred warm-up,

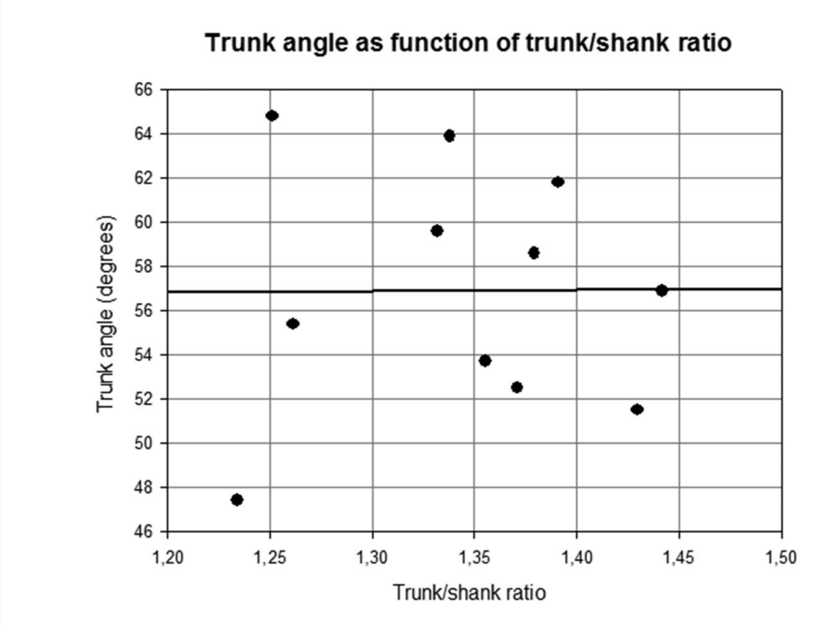

Figure 8. Simple linear regression between trunk/thigh ratio and trunk angle in the parallel squat.

primarily including stretching, cycling, and squatting, without any time limit. During squat warm-up, the subjects received instructions on how to stand in the starting position, with feet pointing straight forward and with the marked distance between their feet. Although this was unnatural for most subjects, this was done to standardize the squat and minimize movements in the frontal plane during the lift.

After warm-up, the reflective markers were placed on the subjects using a double-sided tape. After placement, subjects had 2 lifts to reach their test weight. During the 2 warm-up sets, squat depth was checked both visually and with motion capture. Depth was then corrected to ensure that subjects reached a minimum of parallel depth. The subjects then performed 3 continuous repetitions while being recorded with motion capture.

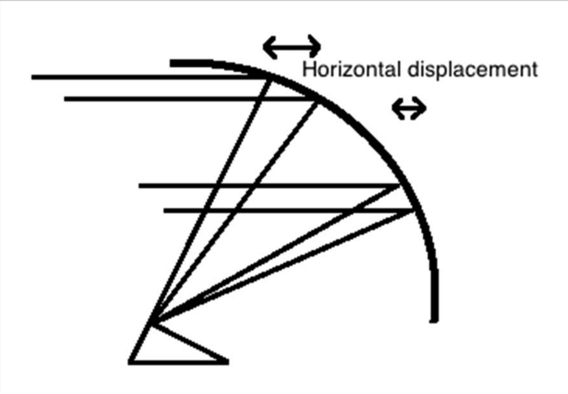

Figure 9. Changes in horizontal displacement by improved mobility with difference in starting range of motion.

After squatting, a standardized WBLT (5) was performed to determine ankle mobility in both ankles (Figure 2). While being monitored from behind, the subjects lunged forward until maximum DF. During the WBLT, subjects were allowed to hold on to the squat rack for support. Maximum DF was identified as the DF just before the heel started moving vertically. Subjects were instructed to keep this position for 3 seconds, then reset and repeat for 3 consecutive repetitions. While performing the WBLT, joint positions were recorded with motion capture for calculation of maximum ankle DF-ROM. Afterward, the test was repeated for the other ankle.

Statistical Analyses

All movements were captured in 3D, but data were analyzed in 2D in the sagittal plane. Positions with maximum DF in the WBLT were found using the visual 3D animation in Qualisys. The timeframe with maximum DF was selected, and position data were extracted from the video. Raw data were loaded into SigmaPlot where an angle average for the timeframe was calculated. The maximum DF was calculated as the anterior angle between the shank and horizontal (shank angle). This process was conducted for both legs, and an average was calculated.

The angles of the squat were calculated for the parallel position. The parallel position was defined as the first frame where the average vertical height of the hip markers became lower than the average height of the knee markers. All subjects performed 3 repetitions, and an average of the segment angles was calculated. A repetition was accepted if the average vertical distance between hip and knee markers, in the lowest position, was within 2.5 cm. This was due to possible errors in the placement of the markers and the fact that the skin moves during movements (26). Studies have also indicated that morphological parallel tends not to be the actual bone parallel (13).

At the PS position, shank and trunk angles were calculated as the anterior angle between the segment and horizontal (Figure 3). The trunk angle was calculated as the angle between a line from the average of the trochanter major markers and the bar marker and horizontal. Shank/thigh, trunk/thigh, and trunk/shank segment ratios were calculated.

Maximum DF in the WBLT was compared with the shank angle in the parallel position of the squat to investigate the relationship between the maximum DF and use of ankle ROM in the PS. Simple linear regression was produced to examine the correlation between trunk angle and maximum DF in the WBLT, and between shank angles in the PS and in the WBLT. Multiple regressions were produced for both the relationship between the trunk angle and the 3 segment ratios and with maximum DF in the WBLT added. Statistical power analysis was performed to test the power of the sample size. Significance level was set to ≤ 0.05 and statistical power for sufficient sample size ≥ 0.80 (Figure 3).

RESULTS

Data presented in Table 1 show the mean of the absolute segment lengths, segment ratios, and segment angles. On average, there was an 11.4 ± 4.4° deficit between maximal shank angle in the WBLT and the PS position. This shows that, on average, the subjects were not able to make use of their maximal ROM during the squat. Furthermore, this was independent of subjects maximal ROM.

Data for all regression models are shown in Table 2. Model 1 shows a significant relationship between the maximum shank angle in the WBLT and PS position ($R^2 = 0.41$, $P = 0.034$). Model 2 shows a significant relationship between the trunk angle and the ankle ROM in the WBLT ($R^2 = 0.45$, $P = 0.024$). Model 3 shows no significant relationship between the segment ratios and the trunk angle. ($R^2 = 0.37$, $P = 0.33$). Combining segment ratios and ankle ROM to predict the trunk angle also failed to reach significance level. The combined effect of the segment length ratios and the ankle ROM is shown in model 4 ($R^2 = 0.6$, $P = 0.18$).

Figure 4 visualizes the correlation presented in model 1. Figure 5 visualizes the correlation presented in model 2. Figures 6–8 present the individual segment ratios correlation with the trunk angle. Post hoc statistical power analysis showed a statistical power of 0.886.

DISCUSSION

The aim of this study was to examine how the DF-ROM of the ankle and the ratios between the thoracic spine, thighs, and shanks influence the kinematics of the back squat. To our knowledge, no previous scientific studies have investigated the biomechanical characteristics of the barbell back squat in relation to ankle ROM and segment ratios for their influence on the trunk angle.

In this study, the lifted weight (75% of 1RM = 102.7 kg.) was substantially greater than weights lifted in 2 studies with similar (75% of 1RM = 76.5 kg.) (1) and almost similar percentage of 1RM (80% of 1RM = 85.4 kg.) (34). This could indicate that test subjects in this study were more experienced with the barbell back squat. Segment lengths were similar to lengths calculated from an anthropometric table (35), and angles were consistent with angles found in other studies with similar conditions (7,9).

The PS was chosen for this study because while squatting, the center of mass must be centered above the midfoot (28). The person squatting must counterbalance the hip moving backward relative to the foot by either leaning the trunk forward or moving the knees forward relative to the foot, which requires dorsal flexion of the ankle. The greatest demand for trunk lean and ankle dorsal flexion is when the horizontal distance between the knee and hip is the greatest, which is in the PS position. Hence, the PS position is anticipated to be the best position to highlight differences in ankle mobility and trunk lean. Furthermore, it is the required depth in the International Powerlifting Federation's (IPF) powerlifting competitions (33). Also, an electromyogram study showed that a PS demands greater muscle activity in the contracting muscles compared with partial squats (14).

Wretenberg et al. (1996) showed no difference in muscle activation between full depth squats and PSs. This indicates that the PS and the full depth squat stimulate the same amount of muscle growth, whereas the partial squat stimulates muscle growth to a lesser degree.

To predict the trunk angle in the PS, it was necessary to find a test for predicting shank angles in PS. In a previous study, Dill et al. (2014) showed a relationship between DF in the WBLT and DF in both overhead squat and single-legged squat. In addition, this study showed a significant relationship between ankle DF in the WBLT and the parallel position of the barbell back squat ($P = 0.034$). This suggests that the WBLT can be used as a valid predictor for the degree of DF in the PS. However, the R^2-value showed that only 41% of the variation in the DF in the PS position was explained by the WBLT. The WBLT showed an average of 47.8 ± 5.7° in DF ankle ROM. This resembles the results found in the study by Dill et al. (2014) and places the average, but not all the test subjects, in the category "limited" ankle mobility.

On average, the subjects tended to have an 11.4 ± 4.4° deficit between their maximal ankle DF in the WBLT and in the PS position. A possible explanation for the difference in use of DF-ROM is that it could be due to the different purposes of the 2 tests. In the WBLT, the subjects' only concern was to push the knee forward while keeping the heel in contact with the ground. During the squat, the main concern for the subjects was to reach the required depth and lift the weight. In addition, this deficit was independent of maximal DF, suggesting a natural deficit between maximal ROM and usage of ankle ROM in the PS. It is unclear what courses this deficit.

For the PS, it was hypothesized that a lower anterior angle between the shank and horizontal would lead to a more upright trunk. This was supported by the findings in this study, showing a significant correlation between shank angle in the WBLT and trunk angle in the squat ($P = 0.024$, $R^2 = 0.45$). This means that the subjects who had greater

DF-ROM tended to squat with a more upright posture, and that ankle mobility accounted for 45% of the variance in trunk angle.

Second, it was hypothesized that greater shank/thigh and trunk/thigh ratios would lead to a more upright trunk. Only the trunk/thigh ratio showed a positive influence on the trunk angle ($B = 683.3$).

The rationale for using segment ratios instead of absolute lengths is that if a person has long thighs, it is impossible to predict the influence on trunk angle by this factor alone. The only thing that matters is how long the thighs are relative to the other segments. If a person's thighs become 10% longer, but the rest of the segments become equally longer, it will not change kinematics and thereby also the trunk angle. This hypothesis is not in accordance with the results in McKean et al. (2012), showing that taller men tended to have a lower trunk angle than their shorter male counterparts. The taller men having longer thighs, relative to the other segments, than the shorter men could explain these results. This would result in a greater posterior displacement of the hip joint relative to the point of balance, resulting in the need for more trunk lean. Even so, this study did not confirm this hypothesis, given that no significant relationship was found between the segment ratios and the trunk angle ($P = 0.33$, $R^2 = 0.37$). However, a possible explanation for this could be the small deviation between subjects' segment ratios.

Even though no significant relationship was found, the multiple regression models showed that the trunk/thigh ratio was the only variable that correlated positively with the trunk angle. This suggests that a longer trunk or a shorter thigh would result in a more upright trunk in the PS. Though segment ratios might have an impact on trunk lean, it must be considered that interpersonal changes in segment lengths will often appear in all segments, causing all ratios to change.

As mentioned above, ranges in subjects' segment lengths, and thereby also segment ratios, were very small. This weakens the predictive effect of the multiple regression and makes it unable to predict trunk lean for subjects varying from the small intervals in data. To prevent this, a test group with a greater range in proportions would have strengthened the predictive capability of the model.

As the primary outcome, a multiple regression was produced to examine how the measured variables affected the trunk angle in which the correlation did not reach the significance level ($P = 0.18$, $R^2 = 0.6$). However, the R^2-value suggests coherence between the variables and the trunk angle, given that it demonstrated the highest value of all the 3 models with trunk lean as the dependent variable. In the model, ankle mobility correlated negatively with the trunk angle, suggesting that a person with greater ankle ROM (lower shank angle) would stand with a more upright trunk during the PS. This finding is in accordance with previous studies and the hypothesis for this study (12,30,31).

In the test, subjects performed 3 repetitions with 75% of their 1RM, even though instructed to perform at 80% of 1RM. This can be explained by a minimum one of the following 2 factors: (a) Subjection to unusual conditions in lifting technique, e.g., feet rotation angle, which could affect muscle activation (34). (b) Not being used to reach an actual PS position, and when trying to, the lift became more challenging because of greater ROM (29). Because no consensus exists in the literature regarding a minimum percentage of 1RM test load, this was not considered to be a problem.

In this study, the PS position was captured during the decent (eccentric part) of the squat. The eccentric phase was chosen because of muscles being able to generate the most force in this phase of the lift (20). It can be hypothesized that the risk of compensatory movements, because of muscle imbalances, are reduced in this phase compared with the ascent (concentric phase). For example, if a subject has strong hip extensors compared with knee extensors, a lower trunk angle might occur in the PS position because the muscle imbalance forces the subject to place a greater load on the hips and less load on the knees.

Intervention studies would be useful to establish whether increase in ankle ROM would lead to altering of the trunk angle. It could be of interest to conclude whether ankle mobility work should be implemented in training to optimize kinematics, reduce risk of back injuries, and establish the amount required to obtain a substantial difference.

Future research should continue the investigation of variables affecting the trunk angle in the squat. Given that the range in data and the number of test subjects were low, more test subjects might create stronger relationships in data. Further investigation is needed to determine whether results found in this study is valid for a wider population, e.g., younger, older, women etc.

In this study, test subjects were asked to perform the squat under regulations. Additional research looking at unregulated squat for subjects with unfavorable prerequisites would be of interest. Such studies would help determine whether these subjects tend to have a greater movement in the frontal plane and also having a wider stance to reduce trunk lean. It would be of interest to explore the complexity of the squat and add more variables to the multiple regression.

Data were analyzed in 2D, thereby movement in the frontal plane is not accounted for in the calculations. Even though the subjects were instructed to keep their feet parallel during the squat, subjects tended to externally rotate their feet slightly, which caused little frontal plane movement to occur (8).

If the markers were placed inaccurately on the subjects, inaccurate segment lengths were measured, which will affect the regression analyses. Only 1 marker was placed at the knee, on the lateral epicondyle of femur. This caused the shank to appear longer and affected the segment ratios to shift toward the shank, often appearing as the longest leg segment.

Flexibility in the hip joint might have affected the results of the study. Inadequate hip flexion can lead to trunk flexion, which can lead to an additional lowered trunk angle. This is due to the trunk being measured as a straight line between the average hip and bar marker position. This flexion of the trunk can emerge from a subject's general stiffness around the hip or a subject not following a standardized warm-up that insured an identical warm-up of the hip joint (19). Occasionally, the video analysis showed a decrease in the distance between the markers on the trochanter majors and the bar. It is difficult to determine whether this was due to trunk flexion or the moving markers were causing the decrease in distance. This error could be determined and minimized in future research by placing more markers on the spine to observe trunk flexion.

In this study, only 11 subjects reached a satisfying depth. Even though the power of the study was sufficient to exceed the minimum level of 0.80, more test subjects could strengthen the correlations in the regressions.

Results in this study were established for male athletes, all of whom had a minimum of 1.5 years of experience with the barbell back squat and strength training in general. These results might be transferable only to subjects of same age, gender, and similar training status. It could be hypothesized that athletes tend to have a different body control and increased or reduced mobility in different joints depending on the sport. Therefore, more studies are needed to confirm whether these results are applicable for other sections of the population.

Subjects in this study squatted with 75% of their 1RM for 3 reps. The kinematic data reported in this study may be altered if the intensity level rises or decreases. A study has emphasized that varying intensities change the speed of movements, which may influence movement patterns. This suggests that speed of the descent in the squat may affect the posture of the PS (11). In this study, execution speed was not controlled. Furthermore, intensity and number of reps and sets were kept at a minimum in this study; thus, the results do not represent the kinematic changes that might occur with fatigue as presented by Hooper et al. (16,17). However, if the joint kinematics of the squat are correlated as presented in this study, an alteration of trunk lean due to fatigue would still alter the shin angle according to the linear regression.

Lastly, it can be hypothesized that subjects with a limited DF would benefit more from improved ankle DF, than a person with greater ROM. A 1° shift forward in shank angle, would result in a greater horizontal displacement of the knee for a shank with a more vertical starting position, given that the knee follows a circular movement pattern. A horizontal displacement would shift the center of mass forward which must be countered by reclining the trunk angle (Figure 9).

Practical Applications

It is widely believed that elevating the heel in the back squat can be an effective way of keeping the trunk more upright during the squat. This is properly due to the extended ROM in the ankle, letting the shank come closer to horizontal.

This study demonstrated that subjects with a greater ROM in their ankles tended to be more upright during the parallel position of the back squat. This suggests that greater ankle ROM raises the trunk angle and thereby reduces shear forces in the trunk. For coaches, the WBLT can be used to examine whether the excessive forward trunk lean is caused by restricted ankle ROM. Athletes demonstrating adequate ankle ROM in the WBLT, but still displaying excessive forward trunk lean in the squat might benefit more from practiciing the movement pattern. By the new knowledge presented in this study, coaches should advise subjects with limited ROM to use weightlifting shoes or to stretch for increased dorsiflexion to reduce trunk lean during the back squat (31). This would serve as a preventive tool against development of future back injuries/problems.

When squatting with a greater forward trunk lean, the demand for activation of the posterior chain will rise. Thereby, it can be hypothesized that a squat with a greater forward trunk lean would lead to lower hypertrophic response in the knee extensors compared with a more upright squat. For athletes with disadvantageous segment ratios and limited DF leading to greater trunk lean who are training for more muscle hypertrophy in the knee extensors, this information might be relevant. These athletes might benefit more from squats in weightlifting shoes or other exercises targeting the knee extensors better because of the possible lowered activation with more forward lean (23).

The results indicated that greater trunk/shank and shank/thigh ratios affected subjects to have a lower trunk angle. Coaches should use this knowledge to determine the possibility for their athletes being exposed to higher stress in the back during the back squat by looking at their morphology.

Knowing the relationship between segment ratios, ankle mobility, and trunk lean, the coach should be able to determine whether limited movement in the back squat is primarily caused by a subject's ankle mobility or morphology. This would then serve as a tool to guide people in modifying their technique.

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