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FRONTAL PLANE KNEE DISPLACEMENT IN BARBELL BACK SQUAT

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The aim of the study was to analyze the ML knee displacement and its influence on barbell tilt and rotation displacement from the back squat. Based on the weight distribution (WtD) test, 13 were in the equal WtD group and 14 were in the unequal WtD group. All subjects performed 75% of 1RM barbell back squat with reflective markers on selected locations for motion analysis. Medial-lateral (ML) knee displacement, barbell tilt and rotation displacements were considered. The results showed a statistically significant difference between groups ($p<0.01$), but no significant difference in ML knee displacement of the left and right sides ($p=0.63$). There were no correlations between ML knee displacement asymmetry and barbell tilt ($p=0.12$) and rotational displacement ($p=0.07$), indicating frontal knee action may not explain unwanted barbell movements in back squat.

KEYWORDS: Back Squat, Knee Kinematics, Barbell Displacement.

INTRODUCTION: Unlike clinical analysis of gait, bilateral resistance exercises, such as the back squat, were assumed to be symmetrical for years (Donnelly, Berg, & Fiske, 2006; Fry, Smith, & Schilling, 2003; McLaughlin, Dillman, & Lardner, 1977). The exercise is used to increase muscular strength in the lower extremity and trunk, and it requires balance and stability to perform it symmetrically between the left and right sides of the body without compromising unwanted bar movement. The back squat is predominantly a sagittal plane exercise with about 30 degrees (°) of ankle dorsiflexion, near/over 90° of knee flexion, depending on the depth of the squat, and 85 to 110° of hip flexion (Donnelly et al., 2006; Fry et al., 2003; McLaughlin et al., 1977). Along with the kinematics of the lower extremity, other studies addressed joint torques, mechanical powers, and superficial muscle activities (Escamilla, Fleisig, Lowry, Barrentine, & Andrews, 2001; Zink, Perry, Robertson, Roach, & Signorile, 2006).

However, practitioners are also interested in other components of the squat kinematics such as frontal plane motion of the knee. After observing how strength and conditioning and weightlifting coaches check their athletes' technique, it appears that many of them use a frontal and/or diagonal position to check lifting technique, including the motion of the knee. From scientific literature, a study reported knee varus and valgus motions activate knee extensor muscles differently (Sogabe, 2009), but no further information on the threshold of the knee varus and valgus range of motion was discussed. Based on the practitioners' viewpoint as well as recent scientific study, it is speculated that carefully observing frontal plane knee kinematics may have an important role on detecting other portions of unwanted movement from the barbell back squat. The current literature, however, has not established a normal range of frontal plane knee displacement and the consequences of that motion on the back squat. Practitioners would then be better prepared to observe and comment on knee motion during the back squat.

Therefore, the purpose of the study was to analyze the medial-lateral (ML) knee displacement characteristics from populations who display equal weight distribution (WtD) and unequal WtD to determine if a difference exists. Further analysis was done by investigating the relationship between the level of knee displacement asymmetry and barbell tilt and rotation during the barbell back squat. The study hypothesized; a) similar ML knee displacement from left and right sides are present from equal WtD group, but not from unequal WtD group, b) unequal WtD group who displays unequal ML knee displacement between left and right sides would be related to higher barbell tilt and rotation during the back squat. The significance of the study would be to share information to practitioners that further attention to frontal plane knee mechanics may be necessary.

METHODS: Thirty male participants volunteered for this study. Initial assessment took place to assess one repetition maximum (1RM), and measure participants' WtD twice for obtaining accuracy of the test. By using Sato & Heise (2012) methods of examining WtD, subjects who displayed less than 4% of WtD were in the equal WtD group, and those who displayed over 6% of WtD were in the unequal WtD group. Participants who displayed less than 4% in one test but over 6% in another, and those who displayed between 4.01 to 5.99 %, were excluded from the study. Based on this initial assessment, equal WtD (*N*=13) and unequal WtD groups (*N*=14) were formed, and three participants were excluded. Demographic data are shown in Table 1. Participants offered informed consent in accordance with the university's Institutional Review Board.

Table 1
Demographic Data of Two Groups

Groups	Age (yr)	Height (m)	Mass (Kg)	1RM (Kg)	WtD test (1st)	WtD test (2nd)
Equal WtD	20.20±1.4	1.76±0.06	82.8±12.80	102.3±25.0	2.31±1.21	3.26±1.83
Unequal WtD	20.14±0.8	1.82±0.07	79.95±8.37	101.8±15.3	7.84±1.94	6.53±3.23
Group comparison *p*	.84	.04	.49	.95	.0001	.004

All participants reported to the laboratory for the back squat test. They warmed-up as they normally would with dynamic stretching and squats with lighter weights leading up to 75% of their 1RM. Then reflective markers were placed at selected anatomical locations and both ends of the barbell. Four cameras were set up in the corners of the laboratory and movements of the reflective markers from the recorded data were digitized using 3D motion analysis software (Vicon-Motus ver. 9.2.1, Vicon, Centennial, CO). Participants performed five repetitions at 75% of their respective 1RM. The raw position data were smoothed with a Butterworth filter and a cut-off frequency determined with an optimization approach by the motion analysis software. For the kinematic data, the knee ML displacement and the barbell angular displacements (tilt and rotation) were calculated by using an average of three repetitions (2^{nd}, 3^{rd}, and 4^{th} repetitions).
The average data from each participant's left and right sides of ML displacement (cm), barbell tilt and rotation angular displacements were averaged for each group. Along with descriptive data, statistical analysis was conducted using 2-factor (legs & groups) ANOVA 1) to determine if there is difference between left and right sides of ML knee displacement, and 2) to identify the difference between equal and unequal WtD groups. It is important to note that interaction effect of the 2-factors was not considered for this purpose of the study. Additionally, the level of asymmetry between left and right sides of ML knee displacement in percentage was derived from the equation used in Sato and Heise (2012). Pearson correlation coefficient was conducted using the ML knee displacement asymmetry to investigate relationships with barbell tilt and rotation angular displacements. All analyses were done with PASW software (IBM Co., NY USA) and alpha level was set at 0.05.

RESULTS: Figure 1 shows the ML knee displacement for left and right knees for both groups. There was a statistically significant difference between the two groups' ML knee displacement ($F(1,25) = 7.31$, $p<0.01$) with a partial eta squared effect size of .23, indicating small difference between the two groups. However, there was no significant difference in left and right ML knee displacement ($F(1,25) = .24$, $p=0.63$). In fact, all participants displayed lateral knee shift from the initiation to the peak descent position of the back squat. Finally, there was no statistical significance in relationship between ML knee displacement asymmetry and magnitude of barbell tilting (r =0.31, p=0.12) and rotation (r =0.35, p=0.07) angular displacements, indicating that unwanted barbell angular displacements from 75% of 1RM back squat are independent from ML knee motions and may come from different biomechanical factors.

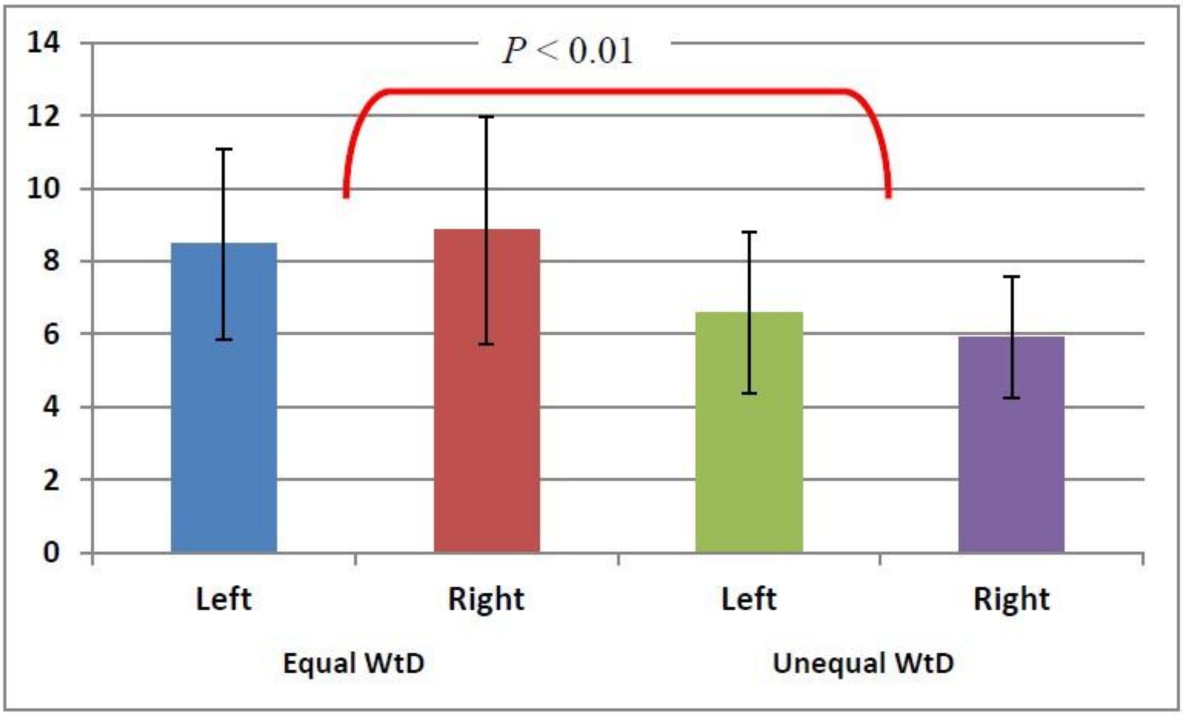

Figure 1: Left and Right ML knee displacement data for equal and unequal WtD groups

DISCUSSION: The purpose of the study was to identify the characteristics of the ML knee displacement from equal and unequal WtD individuals to determine the difference in knee motions. The first hypothesis was partially supported by having a statistically significant group difference on ML knee displacement. Specifically, the unequal WtD group displayed shorter range of linear displacement on both left and right knees as compared to equal WtD group by approximately 2 to 3 cm (see Table 2). While the difference between the two groups was statistically significant, the magnitude of the effect is quite small as evidenced by the effect size (.23). Although it was not a main aim of this study, it is important to note that there was no statistical difference between left and right knees' ML displacement, showing both knees move to lateral direction during the back squat in relatively the same magnitude.

The second part of the analysis was to investigate the relationship between the level of knee displacement asymmetry and barbell tilt and rotation angular displacement from the barbell back squat. This hypothesis was not supported. The relationship between ML knee displacement asymmetry and two planes of barbell displacements were low and statistically insignificant indicating that the unwanted barbell movement in frontal and transverse planes during the back squat was not directly associating with the frontal plane of knee movement. This does make sense as both groups' knees were laterally shifting about the same range regardless of difference in the level of tilting and rotational displacement. Previous research by Sato and Heise (2012) established a connection between WtD asymmetry and increased barbell tilt and rotation, but it appears that ML knee displacement asymmetry does not have the same connection. Future study may need to focus on individuals who display excessive level of ML knee displacement asymmetry to identify its effect on the barbell displacement. These results also lead to additional questions on where the unwanted bar movements are coming from, which may prompt future investigators to examine the kinematics of axial regions (trunk, pelvis, and hip).

CONCLUSION: The results of this investigation establish a basis for future research, but also may provide technical implications for strength and conditioning practitioners. The barbell back squat is frequently utilized for its effects on increasing lower extremity strength and joint movement symmetry seems to be a desirable quality. Knee joint kinematics are often observed in efforts to fix unwanted and faulty weightlifting movements, but perhaps practitioners should look at additional locations. ML knee displacements and asymmetry may still play a role in unwanted squatting movements, but the cause of the unwanted movements may also be multifaceted.

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