
INFLUENCE OF WEIGHT DISTRIBUTION ASYMMETRY ON THE BIOMECHANICS OF A BARBELL BACK SQUAT

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ABSTRACT

Sato, K and Heise, GD. Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *J Strength Cond Res* 26(2): 342–349, 2012—The purpose of this study was to investigate the influence of weight distribution (WtD) asymmetry on the biomechanics of a barbell back squat. This study included 2 groups of trained individuals who were separated based on a WtD test ($n = 14$ in each group). They performed the barbell back squats with 2 resistance levels (60 and 75% of 1 repetition maximum) to measure vertical ground reaction force (GRF), tilting, and rotational angular bar displacements. A symmetry index (SI) score of the vertical GRF and the 2 bar displacements were examined to identify the group difference. Results showed that the unequal WtD group displayed a higher vertical GRF SI score ($p < 0.05$) and greater degrees of the tilting ($p < 0.05$) and rotational ($p < 0.05$) angular bar displacements. The 2 resistances did not influence the magnitude of the dependent variables, and no interactions were found. The unequal WtD captured at the WtD test carried over to the SI score during the back squat test. The unequal WtD was also a partial factor of displaying greater bar displacements. The lack of postural control to distribute body weight evenly should be treated properly to gain levelness before participating in high volume of resistance training, and coaches should be conscious of moving in a symmetrical fashion with minimal bar displacements in tilting and rotational manner.

KEY WORDS bar movements, kinematics, kinetics, resistance training

INTRODUCTION

The barbell back squat is a popular exercise and is used to increase muscular strength in the lower extremity and trunk, and it is often used in strength and conditioning and rehabilitation programs (7,12,20,25).

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The barbell back squat requires balance and stability to perform it symmetrically between the left and right sides of the body. Unlike gait studies with an extensive history of examining asymmetry issues, bilateral resistance exercises, such as the barbell back squat, are often assumed to be symmetrical between both sides of the body (3,8,16,17).

The basic biomechanics of the barbell back squat were first analyzed among elite level power lifters over 3 decades ago (16,17). Typical image analysis at the time was a 2-dimensional (2D) approach to establish a baseline of biomechanical characteristics. The barbell back squat is characterized as a sagittal plane movement and lower extremity joints are primary sources of the movement: dorsiflexing the ankle about 30°, flexing the knee to near 90°, and flexing the hip to a range of 85–110° as a lifter reaches peak descent position (3,8,16). Joint kinetic analyses were also performed to understand the mechanical loads in the lower extremity joints, and from those, the greatest joint torque was identified at the initiation of the ascent phase of the squat (6,17).

Postural control can be an important component when performing bilateral exercises, especially when there are external loads involved. Postural control has been examined to understand balance ability in certain body positions such as quiet standing, tandem stance, and seated position (9,15,21,24). The weight distribution (WtD) test is a specific assessment used to examine symmetry while standing quietly in an upright position. Testing WtD symmetry has not received much attention, especially in a practical setting such as when healthy subjects perform an exercise that demands symmetrical motion. During quiet standing, it has been shown that individuals tend to distribute weight unequally because they develop a “habit” of favoring 1 side for greater acceptance of body weight (BW) (9,15,21). This habit may seem a minor issue in quiet standing, but it may also extend to potentially unwanted movement patterns during bilateral resistance exercises. Even though the bilateral differences on the squat have been studied for individuals with reconstructive knee surgery (22), it is unclear if WtD asymmetry has an influence on the biomechanics of the squat for active young adults who regularly participate in resistance training.

A recent study used healthy, recreationally trained individuals to analyze the bilateral difference of the lower extremity joint

torques when performing the barbell back squat, but the researchers did not mention how individuals developed the asymmetry in the joint torques (6). Furthermore, it is also questionable to what extent unequal WtD contributes to compensations in biomechanical variables when performing the barbell back squat. There is a need to investigate whether WtD asymmetry may influence bilateral asymmetry in bilateral exercise. Therefore, the primary purpose of this study was to investigate the influence of WtD asymmetry on the biomechanics of the barbell back squat. Specifically, this experiment examined subjects who displayed an unequal WtD, to determine if that asymmetry carries over to the performance of the squat, when vertical ground reaction force (GRF) was examined. Additionally, this study determined whether barbell angular displacements in the frontal plane (tilting angle) and the transverse plane (rotational angle) were present during the barbell back squat and whether those variables differed between the 2 groups. The study hypotheses were as follows: (a) unequal WtD group displays greater asymmetry in the vertical GRF, and greater tilting and rotational angular displacements of the bar, (b) as the resistance level increases from 60 to 75% of 1 repetition maximum (1RM), the vertical GRF asymmetry and bar displacements increase for both groups, and (c) as the resistance level increases, vertical GRF asymmetry and bar displacements for the unequal WtD group increase to a greater level as compared with that in the equal WtD group.

METHODS

Experimental Approach to the Problem

This study examined whether the influence of WtD asymmetry exists on the vertical GRF and bar displacements in the barbell back squat. All the subjects performed 60 and 75% of 1RM barbell back squat during a single data collection. Vertical GRFs were measured for the left and right sides of the body and represented as a symmetry index (SI), and tilting and rotational angular displacements represent the bar movement during the barbell back squat. The dependent variables were compared between 2 groups and between 2 resistances for the main effects, and an interaction of the group and resistance was also examined.

Subjects

Twenty-eight subjects volunteered for this study. They were recruited from intercollegiate athletic teams and from collegiate sports club teams during their off-season period. The subjects were college aged and were participating in resistance training, including barbell back squat, for 5–7 years depending on when

they started training under qualified supervisors. During the first visit to the laboratory, they signed an informed consent form and completed a series of questionnaires about injury history, resistance training experience including their sports participation, and limb dominance. Then, the primary investigator measured height, body mass, leg-length, and quadriceps angle of all the subjects. The purpose of the questionnaires and anthropometric measures was to understand how familiar the subject was with the barbell back squat and to identify whether potential subjects possessed unwanted physical characteristics such as unequal leg length that may cause bilateral asymmetry. The demographic and anthropometric data of each group are presented in Table 1. A group comparison based on the independent *t*-tests indicated similar characteristics in both groups because there were no statistically significant differences ($p > 0.05$) except in the WtD test ($p < 0.01$). It is important to note that there was only 1 female participant in this study. She was not excluded from the study because her initial assessment data met all criteria, and she was not an outlier in all categories. All the subjects were free from injury for at least 3 months from the time of testing and offered consent in accordance with the university's institutional review board for the use of human subjects in research.

Instrumentation

Two portable force plates (PS-2141, PASCO Scientific Inc., Roseville, CA, USA) were used during the WtD test and the 2 squat tests. The force plates measured $4.5 \times 35 \times 35$ cm and have a mass of 4.0 kg. The force plates were connected via a short cable to a data logger (Xplore GLX: PS-2002, PASCO Scientific Inc.), which was connected to a laptop computer to display the vertical GRF values (Figure 1). A commercial 1-dimensional (vertical) portable force plate is relatively new to scientific studies. A recent study conducted a series of validation tests on the instrument (4). Three methods of validation showed high correlations and very low coefficients of variability (CV) in

TABLE 1. Group demographic and anthropometric data.*†

| Variable | Equal WtD (<i>n</i> = 14) | Unequal WtD (<i>n</i> = 14) | <i>p</i> Value |
|--------------------------------|-------------------------------|---------------------------------|----------------|
| Age (y) | 20.4 ± 1.3 | 20.1 ± 0.8 | 0.60 |
| Body height (m) | 1.71 ± 0.28 | 1.67 ± 0.39 | 0.80 |
| Body mass (kg) | 84.6 ± 12.2 | 82.5 ± 9.80 | 0.62 |
| Tested 1RM (kg) | 102.3 ± 24.7 | 101.8 ± 15.3 | 0.95 |
| Relative strength (1RM per kg) | 1.21 ± 0.24 | 1.25 ± 0.27 | 0.51 |
| WtD test | 2.01 ± 0.98 | 7.83 ± 1.94 | 0.01 |
| Dominance | L = 2, R = 12 | L = 4, R = 10 | |

*1RM = 1 repetition maximum; WtD = weight distribution.

†Age, body height, body mass, tested 1RM, relative strength, and WtD test are presented as mean ± SD and *p* values are the result of independent *t*-tests.

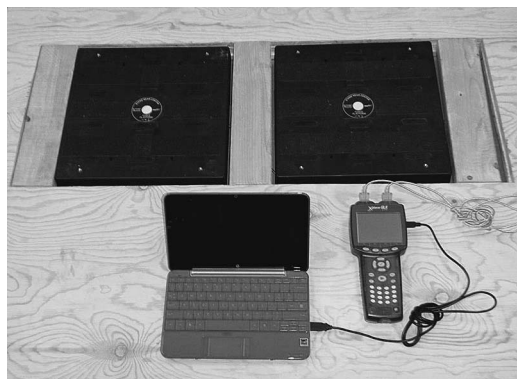


Figure 1. Connection of portable force plates and Xplore GLX to a laptop PC.

(a) the linearity of the force value ($r = 0.999$), (b) the regional dependencies of the surface of the force plate ranging from 0.032 to 0.049% of CV ($\sim 3\text{--}6$ N), and (c) the similarity of the force values when the force plates are placed on a larger force plate ($r = 0.999$).

Four cameras were placed in the 4 corners of the Human Performance Laboratory. They were placed at approximate heights of 2 and 3 m away from the performer. A calibration device with $1.26 \times 1.08 \times 0.90$ m (X , Y , and Z , respectively) and containing 17 markers with known coordinates was used to calibrate the cameras (Vicon, Centennial, CO, USA). Along with the 17 spherical markers of known spatial coordinates, the portable force plates were placed directly underneath the calibration device with known coordinates of the Z -axis pointing vertically, the Y -axis pointing forward, and the X -axis pointing lateral sides of the performer to decide system translation and rotations (Figure 2). In the calibration process for motion data, an average volume error of 0.3% was achieved.

Procedures

During the first session, potential subjects came to the laboratory, signed a consent form, and answered questionnaires. When they met the criteria, they were tested for the determination of 1RM barbell back squat. They performed a series of dynamic warm-up exercises and back squat with lighter loads. During the warm-up, all the subjects lifted heavier weights gradually and attempted the heaviest weight they could possibly lift to identify their 1RM. Visual inspection during the 1RM test confirmed that all the subjects had sufficient lifting experience under qualified supervisors to learn the squat technique. All the subjects came back for data collection a week after the 1RM test. During the second visit to the laboratory, a WtD test was conducted, and the qualified subjects were separated into 2 groups based on the test results. The subjects were asked to

stand quietly on the force plates (1 foot on each). This is a commonly used standard procedure for WtD test in a static standing position (9,15,21). The primary investigator visually observed to confirm that a midline of the body was between the 2 force plates before the vertical GRF measurement (Figure 3). Vertical GRF data were collected at a sampling frequency of 100 Hz for 5 seconds. The WtD was determined by the mean vertical GRF from the last 3 seconds of the 5 second trial (i.e., 300 data points were averaged). The mean vertical GRF between the left and right sides were used to calculate an SI score. The following equation was used because it was used in past studies (23):

$$\text{SI score} = \frac{(\text{higher value} - \text{lower value})}{\text{total value}} \times 100\%.$$

For example, if the subject weighed 500 N, and left = 275 N, right = 225 N, the SI score was 10%.

If the SI score was $>6\%$, they were included in the unequal WtD group. If the SI score was $<4\%$, they were put in the equal WtD group. If the subjects scored between 4.01 and 5.99%, all biomechanical data were excluded from the analysis to clearly separate the 2 groups. This criterion of $>6\%$ WtD asymmetry was a modified version of that previously introduced by Anker et al. (1) to quantify a good and bad WtD. The primary investigator did not report the results of the WtD test to the subjects before the squat tests to avoid any influence on their performance.

After the WtD test, a verbal explanation was provided to the subjects about the 2 squat tests. All the subjects were asked

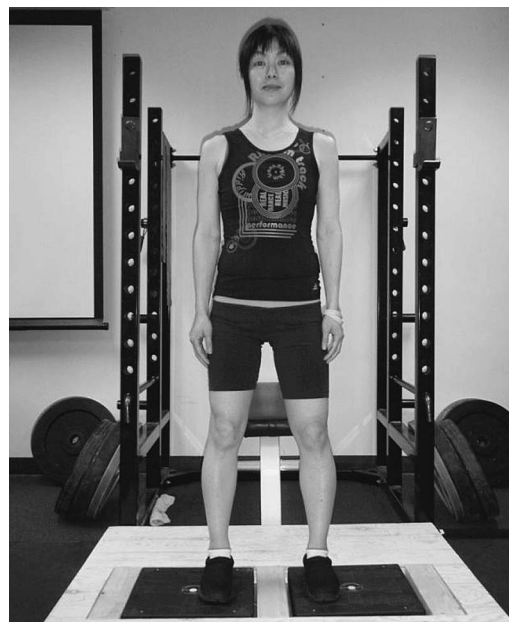


Figure 2. Weight distribution test on the force plates.

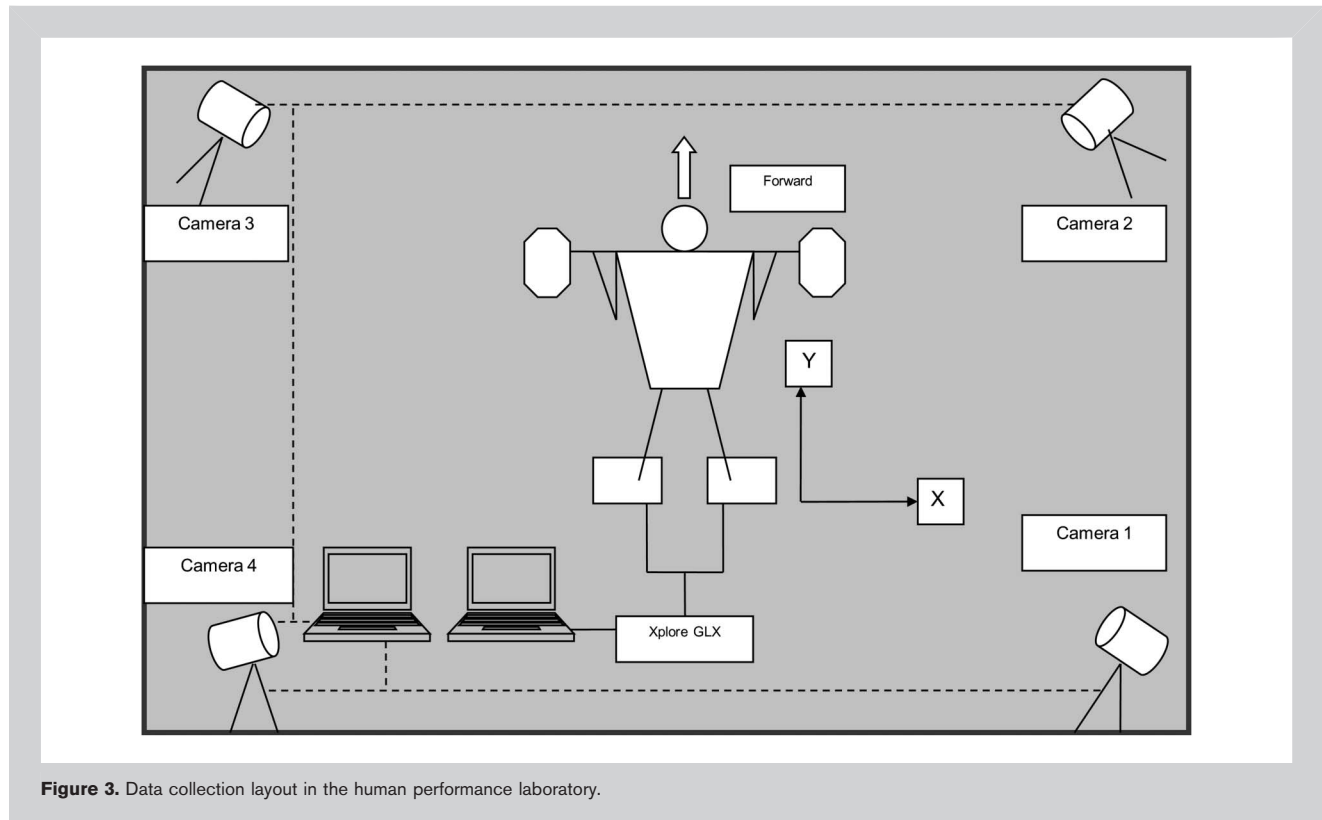


Figure 3. Data collection layout in the human performance laboratory.

to perform 2 sets of 5 repetitions of the 60 and 75% of 1RM back squats. All the subjects performed 60% of 1RM first, followed by 75% of 1RM. Going from lighter to heavier loads was a common training program for all the subjects; therefore, this order was used for this study. A rest period of 2–5 minutes was given between sets and when going from 60 to 75% of 1RM squat tests. Before data collection, all the subjects were asked to stretch in a fashion similar to what they normally do before athletic activity. Similar to the first visit for the 1RM test, they performed a series of dynamic warm-up exercises and back squat with lighter loads.

A metronome was used to control the performer's squat speed. This study used a slow-paced squat, because the subjects were instructed to perform it with a rhythm of 2–1–2–2 count (2 counts down, 1 count at bottom, 2 counts up, and 2 counts rest, and repeat). One count was considered as 1 second on a metronome setup. The rhythm being used in this study was similar to that in a recent study that investigated the influence of squat speeds on selected biomechanical variables (11). By regulating the movement speed, unwanted accelerations are controlled during the squat tests. Varied squat speeds have been shown to display altered body control, and increases or decreases in the sway of spinal alignment (10). The standard position of stance width being slightly wider than shoulder width and toes pointing slightly outward was used as described by Escamilla

et al. (5). All the subjects squatted down to a position where thigh segments were parallel to the floor on each repetition.

After stretch and warm-up, the subjects set to the starting position and performed the squat with the verbal signal of “3–2–1, go” given by the primary investigator. After completing 5 repetitions, they placed the barbell back on the squat rack. They repeated this set one more time and then performed the 75% of 1RM trials with an identical procedure. The rest period between the set was 2 and 5 minutes depending on the subject's need.

Statistical Analyses

Because reflective markers were placed on both ends of the barbell, movements of the markers from the recorded data were digitized using automatic point-tracking software (Motus ver. 9.2.1, Vicon, Centennial, CO, USA). The position data were then smoothed with a Butterworth filter and a cut-off frequency determined with an optimization approach within the motion analysis software (3 Hz). By using the direct linear transformation methods (26), 3-dimensional (3D) coordinate data were derived from the individual 2D images of each camera. The barbell angular displacements were calculated using an average value of 6 repetitions, from the 2 sets of the last 3 repetitions. This was necessary to minimize the error of measurement from each individual. As they performed 5 repetitions, the first 2 repetitions were

TABLE 2. Vertical GRF asymmetry score comparison.*†

| | 60% of 1RM | 75% of 1RM |
|-------------------|-------------|-------------|
| Equal WtD group | 2.09 ± 1.55 | 2.53 ± 1.79 |
| Unequal WtD group | 4.44 ± 2.04 | 4.93 ± 2.62 |

*GRF = ground reaction force; WtD = weight distribution; 1RM = 1 repetition maximum.

†All values are expressed in symmetry index percentage.

TABLE 4. Rotational barbell angular displacement comparison.*†

| | 60% of 1RM | 75% of 1RM |
|-------------------|-------------|-------------|
| Equal WtD group | 1.74 ± 0.46 | 1.80 ± 0.52 |
| Unequal WtD group | 2.46 ± 0.49 | 2.67 ± 0.68 |

*WtD = weight distribution; 1RM = 1 repetition maximum.

†All values are expressed in degrees.

excluded as “dry repetitions” and the last 3 repetitions were considered for calculation purposes.

The vertical GRFs were recorded simultaneously and independently from each foot throughout a repetition. The total vertical GRF from each platform was summed over the period of 1 repetition and divided by the number of samples and then divided by the participant’s BW (6,19). Identical to kinematic data calculations, the value was the average of 6 repetitions (from 2 sets of the last 3 repetitions) to identify the average of the vertical GRF for each participant in both groups. Then, the vertical GRF values from each force plate were used to calculate the SI score to quantify the asymmetry between the left and right sides.

Even though this study contained multiple dependent variables, the primary interest of the study was to identify the differences with individual dependent variables. Separate analyses of variance (ANOVA) for each dependent variable were used for this study. Three separate 2-factor (group and resistance), 2 × 2 repeated measure ANOVAs were used to identify the differences between the groups and between the resistance levels, and an interaction effect. Statistical significance was set at $p \leq 0.05$.

RESULTS

Vertical Ground Reaction Force

It was hypothesized that mean group data would be different and a greater level of asymmetry would be observed as the

TABLE 3. Tilting barbell angular displacement comparison.*†

| | 60% of 1RM | 75% of 1RM |
|-------------------|-------------|-------------|
| Equal WtD group | 1.59 ± 0.28 | 1.68 ± 0.44 |
| Unequal WtD group | 2.34 ± 0.80 | 2.60 ± 0.70 |

*WtD = weight distribution; 1RM = 1 repetition maximum.

†All values are expressed in degree.

resistance level increased. For this measurement, a statistically significant main effect for group was found ($F[1, 26] = 10.26, p > 0.05$). A resistance main effect was not statistically significant ($F[1, 26] = 2.45, p = 0.13$), and an interaction effect between group and resistance was also not statistically significant ($F[1, 26] = 0.01, p = 0.93$). Table 2 represents the measurements of the vertical GRF asymmetry score data.

Tilting Angular Bar Displacement

It was hypothesized that mean data of the 2 groups were different, and a greater level of asymmetry is captured as the resistance level increases from 60% to 75% of 1RM. A main group effect was found as statistically significant ($F[1, 26] = 18.98, p < 0.05$); however, a main effect for resistance was not statistically significant ($F[1, 26] = 2.44, p = 0.13$). An interaction effect between group and resistance was not found as significant ($F[1, 26] = 0.59, p = 0.45$). Table 3 represents the measurements of the tilting angular displacement data.

Rotational Angular Bar Displacement

It was hypothesized that the 2 groups would differ and that a greater level of asymmetry is captured as the resistance level increases from 60 to 75% of 1RM. For this measurement, a main effect of group was found as statistically significant ($F[1, 26] = 20.89, p < 0.05$), but a main effect of resistance was not statistically significant ($F[1, 26] = 1.43, p = 0.24$). Finally, an interaction effect between group and resistance was not found as statistically significant ($F[1, 26] = 0.45, p = 0.51$). Table 4 represents the measurements of the rotational angular displacement data.

DISCUSSION

The primary purpose of this study was to investigate the influence of asymmetrical WtD on the biomechanics of the squat. Results revealed that the equal WtD group, as compared with the unequal WtD group, demonstrated less asymmetry in vertical GRF, and less barbell displacements at both 60 and 75% of 1RM barbell back squat. This indicates that the equal WtD group is able to maintain their WtD more evenly and hold the bar more evenly stable while performing light and moderate intensities of the barbell back squat. This

study was also designed to examine the level of asymmetry in 2 resistance levels of squat. None of the dependent variables were influenced by the resistance levels nor was there an interaction between the independent variables. This signifies that different resistance levels were not influential to change the SI scores and bar angular displacements.

This study was the first to use the SI to identify bilateral asymmetry in a bilateral resistance exercise task. As mentioned in Introduction, it was often assumed that bilateral symmetry exists in exercises such as the squat (3,5,8,16,17). The results of this study showed that bilateral symmetry should not be assumed in experienced lifters. Furthermore, asymmetry in a quiet standing pose transferred to the back squat when considering the vertical GRF.

Healthy, trained individuals who possess unequal WtD showed greater asymmetry in the vertical GRF during squat tasks. The results suggest that the vertical GRF asymmetry identified during quiet standing carries over to the squat exercise, with no change as external load was added. The difference of the WtD test scores seems reasonable given that the average WtD test score differed by >5% between the 2 groups (Table 1).

It has been shown that a vertical GRF asymmetry exists in healthy, trained individuals (6,13,19). Additionally, Impellizzeri et al. (13) reported a high reliability of the vertical GRF asymmetry measures (intraclass correlation coefficient = 0.91), showing a person's inclination to favor one side consistently. This strengthens the appropriateness of measuring and analyzing both sides of the body, instead of assuming that they are equal. Flanagan and Salem (6) investigated the vertical GRF asymmetry during the back squat at 4 different resistance levels (25, 50, 75, and 100%). Recreationally trained participants ($N = 18$) exhibited an average 6% asymmetry ($p = 0.002$), because they reported that 17 out of the 18 participants (94.4%) claimed themselves to be right-side dominant and possessed a larger magnitude of weight distributed to the left side. This study showed a comparable trend because 20 out of 28 (71.4%) showed a greater WtD on the functionally nondominant side during the WtD test and the 2 squat tasks. Even though a static WtD test was not conducted in their study, their results were similar to the results of this study with regard to the vertical GRF asymmetry. Flanagan and Salem (6) also showed that the level of the vertical GRF asymmetry was unaffected by the resistance levels ($p = 0.37$). This was also consistent with the findings of this study.

Most experienced lifters should notice an unevenness of the bar-end positions between the left and right sides and therefore notice bar tilt. Even though it is unknown as to how this compensation occurs, there may be multiple factors involved in the motions. In this study, influence of the unequal WtD was the main focus to identify a greater angle of the tilting displacement with 2 resistance levels of the back squat.

Tilting 1 side downward and the other upward was captured in the range of 1.17–2.03° in the equal WtD group,

and 1.14–3.87° in the unequal WtD group at 60% 1RM back squat. At 75% 1RM back squat, the range of the equal WtD group was 0.95–2.60°, whereas the unequal WtD group showed a range of 1.76–3.58°. Based on visual observation, all the participants started with the bar parallel to the floor. Motion analysis data confirmed this observation, indicating a deviation of $< \pm 0.7^\circ$ of tilt at each lifter's initial position. Tilting the barbell during the squat was visually noticeable from the posterior view on those who displayed the tilt, especially as they reached bottom.

However, after further observation of each participant's data, the bar was not tilted downward to the nondominant side. In other words, the downward tilting side is not necessarily the heavier WtD side during the barbell back squat. This leads to a question of how the bar tilt was affected by the unequal WtD. There may be a further analysis needed to understand how the WtD asymmetry leads to the bar tilt.

Similar to barbell tilt, there was a group difference in barbell rotation but no difference between resistance levels. Rotating 1 side of the barbell in the anterior direction and the other side in the posterior direction was captured in the range of 1.20–2.74° in the equal WtD group, and 1.21–3.24° in the unequal WtD group at 60% 1RM back squat. The range was captured from 1.23 to 3.01° in the equal WtD group, and from 1.78 to 4.14° in the unequal WtD group at 75% 1RM back squat. Motion analysis data confirmed this observation, indicating a deviation of $< \pm 1.2^\circ$ of tilt at the initial position. Rotating the bar during the squat was not visually noticeable because the rotation occurs about the vertical axis of the body. However, further data observation revealed that the maximum rotation typically occurred during the descent phase and toward the peak descent position. It is important to note that there was no discernable trend such as rotating the bar forward to the dominant side. This leads to another unanswered question on how the bar rotation was affected by the unequal WtD. Coordination of segmental contributions to bar motion would address the reason(s) that lifters with unequal WtD display greater bar motion.

During a previous 2D squat pilot study, some subjects were noticeably rotating the bar as they squatted. The bar rotation was relatively easy to observe if a camera was positioned perpendicular to the lifter's sagittal plane. This observation was captured from 1 side of the weight plate moving to anterior direction while the other side was moving to the posterior direction. Thus, it confirms that the bar was moving in the transverse plane. Even though 3D was used in this study, a 2D view such as a sagittal plane view could be used to capture the bar rotation in a qualitative analysis. Therefore, coaches and athletes could use a sagittal plane view to observe the unwanted bar rotation.

Several recommendations for future research have been developed through the experience of this study to identify effects of WtD asymmetry on biomechanics of a barbell back squat. First, 60% of 1RM could be considered as warm-up intensity for well-trained individuals, and 75% of 1RM could

be light load for them as well. During the pilot study ($N=10$) using 80% of 1RM, squat speed preference varied depending on subjects' experience. Varied squat speed is known to alter squat kinematics significantly (10). Therefore, a lighter load was necessary to allow the subjects to better control squat speed. The subjects who were recruited for this study represented healthy college-aged individuals who participate in competitive sports. Thus, the results of this study may be representative of athletically active adults but not of expert lifters. Higher loads such as 85 and 90% would be more appropriate for lifters with greater experience. Second, it is imperative to repeat the analysis with different samples. Future studies should incorporate a population that represents relative beginners in resistance training, which may include young lifters who are being introduced to resistance training, or inactive adults pursuing a healthier life style by participating in resistance training.

Because bar movements are relatively new variables to be observed in the squat study, repeating these measurements is recommended to ensure the reliability of barbell angular displacements. In this study, the 2 angular displacements were different between groups but not between resistance levels. Although cause and effect cannot be shown with the statistical design used in this study, unequal WtD appears to be a factor that contributes to greater bar tilt and rotation. However, the group mean difference of 1° questions the practical significance because it may be difficult to visually distinguish. Lastly, muscle strength asymmetry in the trunk and both upper and lower extremities may be a possible reason behind the tilt and rotation of the bar and asymmetry in vertical GRF. This bilateral muscle strength asymmetry could be analyzed in future studies. As mentioned in the Introduction, many individuals develop "habits" depending on their life styles, and the sports they participate in to create the bilateral asymmetry (9,15,21).

PRACTICAL APPLICATIONS

Based on the results of this study, an assumption for bilateral symmetry of the vertical GRF should not be made. Strength and conditioning coaches should be aware that there are possible asymmetrical movements in bilateral exercises. Unequal WtD that was captured during the static WtD test carries over to the back squat. Because the unequal WtD led to the results of a higher SI score of the vertical GRF, proper exercises to reduce the amount of WtD asymmetry should be prescribed. Unequal WtD is identified by shifting BW to 1 side (9,15,21), and those individuals displaying unequal WtD may experience difficulty in maintaining a centered center of pressure (CoP) location. Based on a clinical study with patients with stroke (24), WtD asymmetry is corrected when proper rehabilitation is provided. It is unknown as to whether this also applies to healthy active college-aged individuals, but correcting WtD asymmetry is highly recommended. For example, single-leg exercises with both stable and unstable surfaces may be beneficial, because 1 study showed

a significant improvement in minimizing medial-lateral (ML) CoP excursion after 8 weeks of functional balance training on stable and unstable surfaces (18). A series of balance exercises leads to a reduced ML weight shift and minimizing the ML weight shift, and keeping the center of mass as close to the midline of a body may be a key to reducing the amount of WtD asymmetry. Coaches can include several balance-oriented exercises into their training program to help reduce the possible sway away from the midline of the body.

Because the unequal WtD group displayed a greater degree of bar displacements, it is important to discuss how the bar displacements are such an essential part of squat mechanics. Unwanted bar movements in weightlifting are categorized by researchers as faulty movements (2,14). Similarly, an excessive degree of bar displacements may compromise the benefits of a squat that should be done with minimum bar sway. Having said that, the extreme bar movements in tilt and rotation during the back squat could be categorized as unwanted bar movements. The unwanted movements of the bar may disturb a training effect. Coaches should monitor the bar movements carefully to minimize the tilt and rotation when athletes perform the back squat. Lastly, because the data show relatively high CVs in some dependent variables, an assumption should not be made that an individual follows a pattern that was identified by researchers' group mean data. Therefore, it is recommended that coaches monitoring and assessing squat motions should realize that a standard template is not appropriate for all athletes.

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