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KINEMATIC CHANGES USING WEIGHTLIFTING SHOES ON BARBELL BACK SQUAT

KIMITAKE SATO,¹ DAVE FORTENBAUGH,² AND DAVID S. HYDOCK³

¹Kinesiology Program, Arizona State University, Tempe, Arizona; ²Biomechanics Laboratory, American Sports Medicine Institute, Birmingham, Alabama; and ³Department of Sport and Exercise Science, University of Northern Colorado, Greeley, Colorado

ABSTRACT

Sato, K, Fortenbaugh, D, and Hydock, DS. Kinematic changes using weightlifting shoes on barbell back squat. *J Strength Cond Res* 26(1): 28–33, 2012—The purpose of this study was to validate a higher degree of foot segment angle by wearing the weightlifting (WL) shoes and to determine the kinematic differences between WL shoes and running shoes during the barbell back squat. College-aged individuals volunteered to participate in this study ($N = 25$). After warm-up, subjects performed 60% of 1RM barbell back squat. Reflective markers were placed on lower extremity joints and end of the bar to create segments to analyze kinematics of the barbell back squat from a 2-dimensional view. Three separate repeated measure analyses of variance were used at $p = 0.05$. Results showed that there was a difference between the footwear conditions; foot segment angle of 3.5° ($p < 0.05$) and trunk lean of 22 mm ($p < 0.05$) were captured when wearing WL shoes. However, thigh segment peak flexion angle was not statistically different ($p = 0.37$). Wearing WL shoes seems to be beneficial in reducing the overall trunk lean, because this position is believed to reduce the amount of shear stress in the lower back area. Back squat with WL shoes also increased foot segment angle and possibly contributes to greater muscle excitation in knee extensors. Weightlifting shoes did not help reach thigh segment closer to horizontal as compared with the running shoe condition. It is recommended that WL shoes be used by those who are prone to displaying a forward trunk lean and who aim to increase knee extensor activation.

KEY WORDS biomechanics, footwear, resistance training

INTRODUCTION

The barbell back squat is a popular exercise to increase muscular strength in the lower extremity and trunk, and it is commonly used in both strength and conditioning (15,23) and rehabilitation

programs (25). At the same time, common injuries in the knee and low back from squat exercises are evident (2). Numerous squat studies have been conducted to identify stress levels in the knee and low back area (6,8,9,21). Past biomechanics research on the barbell back squat analyzed mechanical differences between high-skilled and low-skilled powerlifters (19,20). More recent publications have examined a variety of biomechanical variables such as joint moments, mechanical powers, muscle activity, and trajectory of the barbell with various stance widths and intensity levels (6,8,18,27). The National Strength and Conditioning Association (NSCA) developed a position statement in 1991 as a guideline for proper squat technique (2). These guidelines are based on the biomechanical findings up to the 1980s; however, these guidelines are still used by strength and conditioning coaches and personal trainers to this day.

To achieve an optimal squat technique, the NSCA position statement addresses several technique principles. These principles include the following: (a) descending in a controlled manner until the thighs reach at least parallel to the floor; (b) keeping the shank segments close to vertical to reduce shear force in the knee joint; and (c) keeping the feet in place and flat on the floor (2). The NSCA position statement also advocates maintaining a normal lordotic posture with the torso as close to the vertical as possible during the entire lift, because a previous study reported that minimizing trunk segment torque reduced lumbar disc shear stress (13). Excessive forward trunk lean has frequently been identified as a common technique error when performing the squat (5,7). A greater degree of the trunk flexion during the squat leads to a higher risk of low back injury by increasing the shear forces in the low back area (4,10,13,14). A greater amount of compressive force on the spine also occurs in the barbell back squat as a result of placing the barbell with additional weights on the upper back (21). Thus, careful supervision to perform a squat using the correct form is highly emphasized in strength training environments.

Weightlifters are highly recommended to wear specialized shoes during competitions and training. Rule 4.2.1 of the International Weightlifting Federation (IWF) technical and competition rules states that the purpose of these weightlifting (WL) shoes (Figure 1) is to protect the lifters' feet and

Address correspondence to Dr. Kimitake Sato, jpnsatok@hotmail.com. 26(1)/28–33

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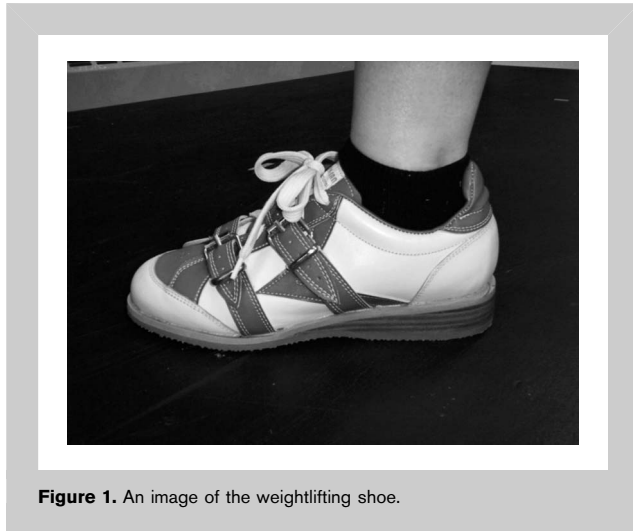


Figure 1. An image of the weightlifting shoe.

provide a stable, firm stance on the platform (16). Most WL shoes are also designed with stiff, noncompressible soles and a raised heel. Although the IWF technical and competition rules state that there is no minimum or maximum height of the soles, the heel is generally raised approximately 2.5 cm in relation to the forefoot to create a plantar-flexed position when standing. Because a previous study found increased knee extensor muscle activity as the decline angle increased (up to 25° declined surface) (18), a greater plantar-flexed foot segment angle created by wearing the WL shoes may be beneficial by engaging greater muscle excitation in the knee extensor muscles.

Although these shoes are well known to weightlifters, they are generally unfamiliar to noncompetitive lifters who perform heavy lifting exercises as a part of a general strength training regimen. For noncompetitive lifters and student athletes at the collegiate level, running shoes or other types of athletic shoes (i.e., shock absorbing and minimal lateral support) are common footwear options when performing Olympic lifting and power lifting exercises. Those who are familiar with WL shoes often denounce the use of running shoes when lifting (3,17). They point out that the soft soles of running shoes are designed to absorb the repetitive shocks from walking and jogging, whereas the hard soles of WL shoes are designed to provide sole and lateral stabilities and allow for greater vertical force production required during heavy lifting (17). Overall, there may be potential benefits by wearing WL shoes for a squatting task.

The structure of WL shoes is believed to support proper squat mechanism by helping the participant to maintain an upright posture, which is essential for reducing shear stress in the lumbar region. Thus, wearing WL shoes may help prevent back-related injuries. However, there is no scientific benefits identified using WL shoes. There is a need to investigate how WL shoes are beneficial to users and to identify the differences in the selected kinematics of the back squat when

compared with running shoe condition. Therefore, the purpose of this study was to determine the differences in selected squat kinematics between WL shoes and running shoes during the barbell back squat. Also, this study was conducted to identify whether WL shoes are biomechanically beneficial without compromising the proper squat technique. It was hypothesized that a higher degree of foot segment angle would be captured because of the heel-raised structure in the WL shoes to promote greater muscle excitation in the knee extensors. It was also hypothesized that squatting with the WL shoes would lead to less anterior displacement of the barbell and less posterior hip displacement because of less trunk lean. This would support minimizing shear stress in the lower back area. Lastly, the thigh segment would be reaching closer to horizontal as the desired squat depth while wearing WL shoes. If WL shoes are a more desirable option to achieving proper squat technique and reducing the risk of squat-related injuries in the back area, such results would be useful to coaches and athletes and to validate the claims of the effectiveness of WL shoes to help lifters.

METHODS

Experimental Approach to the Problem

Determining the possible kinematic differences between wearing WL shoes and running shoes when performing the back squat is necessary to understand how WL shoes help achieve an optimal squat technique and reduce the risk of injury when compared with running shoes. This study compared the kinematics of the barbell back squat when wearing WL shoes and running shoes. The independent variable was the footwear condition, and the following dependent variables were selected to determine the kinematic differences: (a) foot segment angle, (b) a combination of anterior barbell displacement and posterior hip displacement, and (c) peak flexion angle of the thigh segment. Those dependent variables are essential for determining the correct squat technique based on the NSCA position statement (2) and are instrumental in understanding injury risks associated with the differing footwear. To examine the variables, repeated measure analysis of variance (RM-ANOVA) was used for each dependent variable to determine the difference between the 2 footwear conditions.

Subjects

Volunteers ($N=25$: male = 20, female = 5) for this study were recruited from intercollegiate athletic teams and collegiate sport club teams during their off-season period (age: 20.6 ± 3.7 years, height: 1.78 ± 0.1 m, mass: 83.4 ± 13.2 kg). The subjects had been participating in resistance training including the barbell back squat for 5–7 years under qualified supervisors. All the subjects were free from injury for at least 3 months from the time of testing. Because the primary focus of the study was to investigate possible kinematic differences between the 2 footwear conditions, additional anthropometric measures (i.e., segment length) were not considered. The

1 repetition maximum (1RM) was done approximately 1 month before the data collection because the 1RM test was done at the beginning of each athlete's off-season training period. All subjects signed an inform consent form after the testing protocol was approved by the university's institutional review board for the use of human subjects in research.

Instrumentation

One 60-Hz digital camera (PV-GS55, Panasonic, Osaka, Japan) was placed at a height of approximately 1.3 m and positioned 5 m to the left of a wooden platform to capture 2-dimensional (2D) movements of each subject in the sagittal plane. Reflective markers were placed on the left side of each subject's fifth metatarsal joint (toe), lateral malleolus (ankle), lateral femoral epicondyle (knee), and greater trochanter (hip) (9,19,20). An additional marker was placed at the end of the barbell. These 5 points created segments of trunk, thigh, shank, and foot (Figure 2). A segment from the hip to the end of the barbell was used to approximate the trunk segment because the end of the barbell is in a fixed position at the shoulder joint (9,19,20). The video data were directly imported into the Vicon Motus version 9.2 software (Centennial, CO, USA) for motion analysis.

Procedures

The data were collected at the university's human performance laboratory. Barbell back squats in both footwear conditions (WL and running shoes) were performed on the same day during the same testing session. The data collection was performed during midmorning for all subjects to avoid the effects of their afternoon workout or right after having a meal. All subjects brought and wore their own shoes that they normally use in the weight room. Many subjects ($n = 17$) wore shoes that were supplied by the university athletic department (New Balance 759). Those shoes are categorized as cushioning shoes based on the shoe structure. Even though the brands were varied among other subjects ($n = 8$),

they brought shoes that were categorized as cushioning shoes. The common characteristics of those shoes are that they absorb vertical shock from high impact because they contain ethylene vinyl acetate mainly in the rear-foot area and have minor lateral support. A pair of Werksan WL shoes (Werksan USA, Moorestown, NJ, USA) was provided for each subject to wear during the testing. After arriving at the laboratory, each subject read and signed an informed consent form. The subjects were then asked to complete any calisthenics typically performed as a warm-up before lifting. Because all the subjects were familiar with the barbell back squat, only a brief instruction was given to ensure that squat speeds during the descent and ascent were similar. Additionally, to ensure a relatively accurate sagittal plane of the squat motion, all the subjects were instructed to place their feet straight, approximately at shoulder width, and directly perpendicular to the camera position (11). If a subject felt uncomfortable with that foot position, practice sets were provided to gain familiarity. Additionally, many subjects were not familiar with WL shoes, and practice sets were provided during the warm-up to ensure their comfort.

To achieve comparable effort from all subjects, all lifts were performed with a relatively light load (1), which was 60% of the subject's self-reported 1RM. Although typical training intensity for all subjects were from 75 to 85% of 1RM during their team training sessions, 60% of 1RM was chosen for this study. 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 (12). Therefore, a lighter load was necessary to match all subjects' squat speed. Additionally,

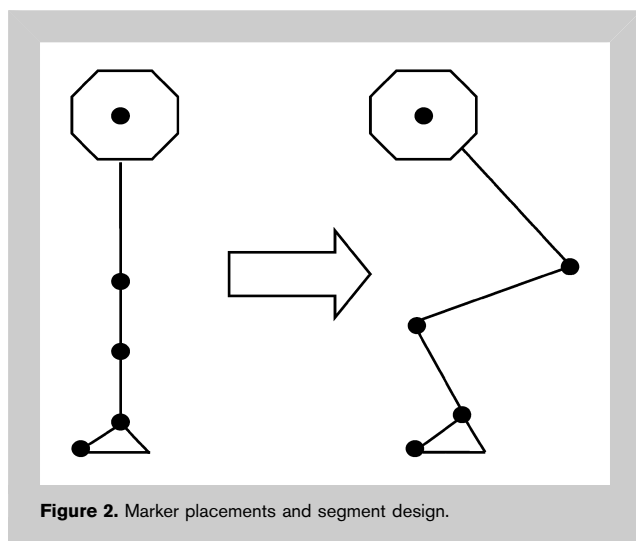


Figure 2. Marker placements and segment design.

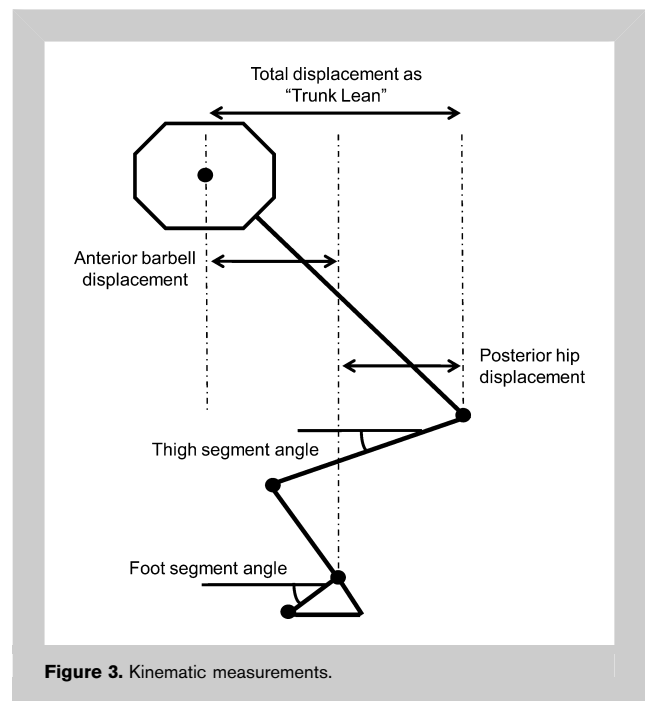


Figure 3. Kinematic measurements.

TABLE 1. Descriptive data of each footwear condition.

Dependent variables	Weightlifting shoes	Running shoes
Trunk lean displacement	216.44 ± 51.05	238.36 ± 52.78
Thigh segment peak flexion angle	20.35 ± 10.13	20.94 ± 10.19
Foot segment angle	38.78 ± 4.02	35.27 ± 5.57

60% of 1RM was chosen because the stance and WL shoes may have been unfamiliar to perform heavy load for some subjects and to minimize the effect of fatigue during the multiple repetitions. The order of the footwear conditions was chosen randomly. For each squat repetition, the subjects began standing erect with the barbell on the upper back (high-bar position) and descended until the thigh segments were roughly parallel to the floor and then ascended back to the starting position. All the subjects performed 2 sets (1 set for each footwear condition) of 5 repetitions. Two repetitions from the 5 repetitions (third and fourth) were averaged and used for calculation purposes. A rest period of 2–5 minutes was given in between each of the trials.

Statistical Analyses

The kinematic data analyzed in this study were reduced and computed directly with the motion analysis software (Vicon Motus version 9.2, Vicon). Anterior bar displacement was calculated from the start position to the maximum displacement the bar traveled in the anterior direction, and the posterior hip displacement was calculated from the start position to the maximum displacement the bar traveled in the posterior direction as well (Figure 3). The 2 displacements were then combined to represent “trunk lean” displacement. Because the maximum anterior bar displacement generally occurs at the peak descent position of the back squat, as does the posterior displacement of hip (9), both measurements were taken at the peak descent position. The peak thigh segment angle was also determined by the angle at the peak descent position of the squat. A thigh segment angle of 0° indicates a horizontal line (9). The foot segment angle was determined by the segment of the marker placement of the toe and ankle (9). All measured variables are illustrated in Figure 3. These 3 dependent variables were selected based on a previous study, which eliminated all intercorrelated variables to reduce the number of dependent variables (24).

The average values of trunk lean displacement, thigh segment peak flexion angle, and foot segment angle for each subject in each footwear condition were used to calculate group data and compared using 1-way RM-ANOVA on each variable. Even though this study analyzed multiple variables, there was no multicollinearity among the variables, so 3 separate RM-ANOVAs were chosen for statistical analysis.

The p value was set at $p \leq 0.05$, and effect size for each statistical data was calculated using Cohen's d method.

RESULTS

Descriptive data for all dependent variables are shown in Table 1. There were significant differences observed in trunk lean displacement ($F[1,24] = 5.57$, $p < 0.05$) with an effect size of 0.42, and foot segment angle ($F[1,24] = 15.87$, $p < 0.05$) with an effect size of 0.72. No significant difference was found in peak thigh segment flexion angle ($F[1,24] = 0.84$, $p = 0.37$).

Trunk Lean Displacement

Table 1 contains mean and SD values for the trunk lean displacement. This significant difference indicates that barbell back squat with WL shoes showed less trunk lean displacement as compared with values shown by the squat with running shoes ($p < 0.05$). The group mean data showed an approximately 22-mm difference.

Peak Thigh Segment Flexion Angle

Table 1 also contains descriptive values for the peak thigh segment flexion angle. No statistical significance was observed, that the peak flexion angle of thigh segment angle did not differ ($p = 0.37$). The group's mean data represented nearly identical values at approximately 20° with respect to the horizontal line.

Foot Segment Angle

The mean and SD for the foot segment angle for the 2 footwear conditions are shown in Table 1. This statistical significance indicates that WL shoes provided a greater foot segment angle when compared with that of running shoes ($p < 0.05$). The difference of approximately 3.5° was captured by wearing the WL shoes.

DISCUSSION

The aim of this study was to identify the squat kinematic differences between WL and running shoes and also to identify the benefits of wearing WL shoes. No scientific studies have investigated biomechanical characteristics of the barbell back squat when using 2 types of footwear to compare the kinematic data. If WL shoes contribute to achieving optimal squat performance and help reduce the risk of injuries based on the kinematic data, this information should be acknowledged. The first hypothesis supported was that the WL shoes could create a higher foot segment angle (38.8°) because of their non-compressible and raised heel structure when compared with the running shoes (35.3°). Although many cushioning types of running shoes also contain a raised heel structure, the cushion would sink the heel and make it closer to the ground with respect to the forefoot segment angle when loaded during the

back squat. The group average difference was 3.5° with an effect size of 0.72, which indicates that WL shoes create a greater degree of plantar flexion assuming the shank segment is in vertical alignment at the initial phase of the squat. Previous research on squatting performed at various declined angles (similar to the effect created by the WL shoes) found increased lower extremity muscle activity, especially in the knee extensor muscles (18). Therefore, wearing the WL shoes may result in engaging greater muscle activity in the knee extensor muscles when compared with wearing running shoes. Having said that, a greater degree of foot segment angle (to some extent) that is created by wearing WL shoes may be beneficial for those who are aiming to increase muscular strength in the knee extensors.

This study also supported the second hypothesis that the back squat with the WL shoe would display less trunk lean displacement when compared with that of the running shoe condition. In reality, there will always be some anterior bar displacement accompanied by some posterior hip displacement during the back squat, which creates trunk lean. The goal, then, is to minimize these movements to reduce the amount of trunk lean. As mentioned in the Introduction, a greater degree of the trunk lean creates increased shear force in the low back area (4,10,13,14). This study demonstrated that the WL shoe condition reduced the amount of forward trunk lean, which ultimately would lead to reducing the risk of low back injury. Accordingly, the position statement of the NSCA also recommends minimizing trunk lean to improve performance and reduce injury risk (2). The present study's findings may help beginners and low-skilled lifters prevent excessive forward lean by wearing WL shoes.

It is important to note that trunk flexion angle was not considered in this study. The authors were interested in observing the amount of forward trunk lean that is represented by the anterior bar displacement and posterior hip displacement. During the pilot study, the trunk segment angle did not start from 0° for all subjects. Based on the data, some individuals initiated squatting from flexed trunk position, whereas others started from the hyperextended trunk position. The varied starting position of the trunk segment would alter the raw value of the trunk flexion angle. Therefore, a combination of anterior bar displacement and posterior hip displacement was reported to represent the trunk lean. Additionally, Sato et al. (24) reported that the combination of bar anterior displacement and hip posterior displacement is weakly correlated with the trunk flexion angle ($r = -0.22$), indicating that the 2 variables are not related to each other. This strengthened the decision on selecting the combination of anterior bar displacement and posterior hip displacement.

Coaches and scientists emphasize that a part of proper squat technique is to descend down until thigh segments reach at least parallel to the floor (2,7). Another aim of this study was to investigate whether the WL shoes allow lifters to more easily attain the thigh at least parallel to the floor

position. This third hypothesis was not supported. During the data collection, the subjects were simply instructed to perform the back squat as they normally would. With 0° set as parallel to the floor, the results showed that the thigh segment reached 20° for both footwear conditions. This outcome indicates that the WL shoes are not necessarily a contributor in allowing lifters to more easily attain the thigh parallel to the floor position during the back squat. Even though the foot segment angle and trunk lean displacement were different, the thigh segment angle did not differ between the 2 footwear conditions. This should be noted and coaches and fitness and healthcare professionals informed that greater flexibility and training experience are essential to reach optimal squat depth.

This study mainly focused on kinematics of the barbell back squat with 2 types of footwear. It is important to report some limitations to further improving the quality of the future investigations. First, because of the nature of the 2D analysis, the foot position was somewhat restricted. The previous 2D squat studies did not mention foot placement nor a possible error of kinematic calculation (9,19,20). Even though 2D analysis has been a commonly used approach in the past studies, 3D may be the solution to minimize the calculation error and to provide freedom of foot placement for subjects. Second, 60% of 1RM is considered a light intensity (1), and the kinematic data reported in this study may be altered if the intensity level increases to subjects' training intensity (75–85% of 1RM). Lastly, further investigations are needed to assess other biomechanical variables, such as joint kinetics, and especially those in the knee joint and low back area should be considered to measure actual joint stress as a result of variations in footwear.

The subjects in this study were college-aged individuals, had 5–7 years of resistance training experience including the back squat under qualified supervisors. The majority of the subjects were male (male = 20; female = 5). Thus, this data outcome may primarily represent that of the young male adult population. Further various populations should be considered, with a focus on female subjects because of their greater lower limb flexibility (22,26), and youth lifters (less overall body strength). Also, individuals with experience using WL shoes should be considered to measure critical biomechanical variables in the knee and low back area to identify the advantages and disadvantages of wearing WL shoes, in future studies. This would expand the representation of populations.

Overall, WL shoes have been around for years, but no scientific studies were conducted to identify physiological and biomechanical benefits when performing Olympic lifts and power lifting exercises. Increased foot segment angle and decreased forward trunk lean by wearing WL shoes could be beneficial for recruiting muscle excitation from knee extensors and help reduce shear forces in the low back area.

PRACTICAL APPLICATIONS

Weightlifting shoes are believed to be an effective footwear choice of weightlifters. This study demonstrated that WL shoes alter the squat technique by minimizing the forward trunk lean displacement and increasing the foot segment angle (placing the ankle in a plantar-flexed position). Personal trainers, strength and conditioning coaches, clinicians, and healthcare professionals may find the current study's findings useful for their practices. Weightlifting shoes contributed to minimize trunk lean, meaning that individuals who have a history of low back injury or want to reduce stress in the back area may likely benefit from wearing WL shoes. A heel-raised footwear can be an alternative to strengthening the knee extensor muscles without compromising the squat technique. The results of this study can also be applied to high school and collegiate weight room environments to help beginner lifters to perform the back squat appropriately by using WL shoes. It is essential for young individuals who start participating in resistance training to learn the correct squat technique. Weightlifting shoes may be a supplemental tool to teach young lifters to keep an upright posture without compromising other kinematic features.

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