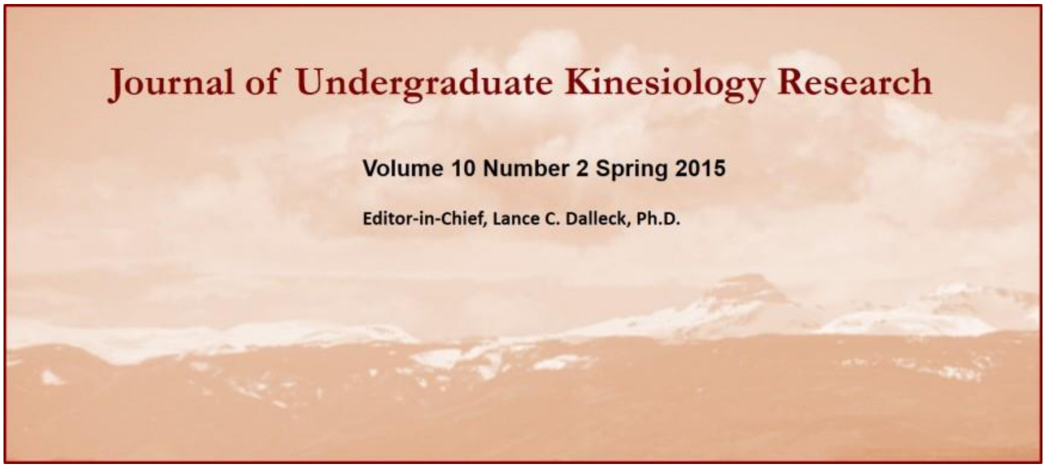

THE EFFECTS OF FOOTWEAR ON FORCE PRODUCTION DURING BARBELL BACK SQUATS

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ABSTRACT

Schermoly TP, Hough IG, Senchina DS. The Effects of Footwear on Force Production during Barbell Back Squats. *Journal of Undergraduate Kinesiology Research 2015*; 10(2):42-51. **Purpose:** Powerlifting shoes claim to help individuals keep their heels in contact with the ground during squatting, ensuring proper force transmission through the rearfoot. The purpose of this study was to determine if a 2.5-lb. weight plate placed under the heels would provide the same advantage powerlifting shoes do during barbell back squats. **Methods:** Twenty healthy males performed five sets of three squats at 75% 1RM in four footwear conditions: low-end powerlifting shoes, high-end powerlifting shoes, cross-training shoes with weight plates under the heels, and cross-training shoes alone (control condition, performed twice). During squats, force plates measured rear- and forefoot force production and an electrogoniometer measured knee angles. Ankle goniometry was performed to measure subject dorsiflexion and plantarflexion as well as talar eversion and inversion. Subjects reported perceived comfort, stability, exertion, and fatigue after completing each set. **Results:** Footwear condition may influence an individual's pre-or post-squat stance ($p<0.05$), but not the depth or nature of the actual squat. Significant differences in the perception of stability between footwear conditions were found ($p<0.05$). However, no significant differences between footwear conditions were observed for ankle goniometry, knee angles, or perceptions of comfort, fatigue, or exertion. **Conclusion:** Neither powerlifting shoes nor weight plates positioned under the heels had any effect on rearfoot force production in this study.

Key Words: heel contact; powerlifting shoes; weightlifting shoes

INTRODUCTION

Barbell back squatting is a common lifting technique used to gain both lower extremity and torso strength, power development, and hypertrophy (1–3). The exercise has also often been used as a method for assessing lower extremity flexibility (4). Proper execution of the lift is critical to gaining strength, flexibility, and preventing injury (5). One important aspect of proper technique includes constant heel contact with the ground (6). Powerlifting shoes include a raised heel and a sole designed to not compress when force is applied, promoting increased heel contact with the ground (7). A raised heel may prove advantageous based on research showing heightened muscle activity in the knee extensor muscles (quadriceps) when performing squats at decline angles (8). Although powerlifting shoes are primarily marketed to athletes who perform back squats regularly, they may also help novice squatters or individuals with reduced lower limb flexibility maintain proper form. Novice squatters may not consider powerlifting shoes as an option given the shoes' limited utility and high price compared to running or cross-training shoes.

Research comparing footwear during barbell back squatting is very limited. Footwear options to consider would be powerlifting shoes, cross-training shoes, or being barefoot when performing squats. In comparing powerlifting shoes to running shoes it has been shown that the powerlifting shoes may be more consistent with correct squat technique in terms of keeping a more vertical shank position (9). Reduced stress on the lower back due to a more erect trunk position has also been seen with powerlifting shoes (9). Both of these findings would suggest the powerlifting shoes enhance squat technique – reducing joint stress and increasing lower extremity muscle activity. No significant differences in terms of squat depth have been found when comparing powerlifting shoes to cross-training shoes (7). However, significantly greater depth in squats was found in comparisons between cross-training shoes and being barefoot (10). The same study found that the majority of the subjects reported a preference for squatting barefoot as opposed to wearing powerlifting or cross-training shoes (10). This suggests that personal preference may play a significant role in footwear selection in addition to kinematic advantages. No literature currently exists comparing various powerlifting shoes to each other.

The purpose of this study was to determine if a 2.5-lb. weight plate placed under the heels would provide the same squat technique advantage powerlifting shoes do during barbell back squats (improved rearfoot contact with the ground via similar heel lift). Weight plates are readily available in gym settings; if a weight plate provided the same benefits as a powerlifting shoe, then it would be a free alternative to powerlifting shoes and might be seen as a useful strategy by novice squatters or individuals who cannot afford powerlifting shoes. It was hypothesized that placing a weight plate under the heel would serve as an equally effective alternative to wearing powerlifting shoes.

METHODS

Participants

This study was approved by the Drake University Institutional Review Board as IRB ID 2012-13013. Twenty males gave written informed consent and completed the entire experiment protocol. The subject pool consisted of males between the ages of 19 and 29 years old. All of the subjects wore shoes between sizes 10 and 13. The activity level of the subjects varied from being well trained in barbell back squatting to having no prior training. The subject characteristics were as follows (expressed in means ± standard error): age = 22.2 ± 0.7 years, height = 182.3 ± 1.8 cm, weight = 82.0 ± 3.7 kg, percent fat = 14.2 ± 1.6 %.

Footwear Conditions

The subjects were given three different types of shoes to perform the squats. A cross-training shoe, the Adidas Falcon Trainer 3 (AFT3), a low-end powerlifting shoe (Low PL), the Adidas powerlift.2 (AP2), and a high-end powerlifting shoe (High PL), the Adidas Adipower Weightlift (AAW) were the shoes provided (Fig. 1). All three models were available to subjects in men's size 10, 11, 12, or 13. The three shoes differed in their forefoot to heel lift as the AFT3 had a lift of 0.157 inches (4 mm), the AP2 had a lift of 0.60 inches (15 mm), and the AAW had a lift of 0.75 inches (19 mm; heel lift information obtained during an online chat with an Adidas representative on 11 September 2014).

These were used to test four footwear conditions: cross-training shoe alone (control), low-end powerlifting shoe, high-end powerlifting shoe, and cross-training shoe with a 2.5 lb. weight placed under the heel (Fig. 1). The 2.5-lb weight plate used in the study had a width of 16 mm; therefore, when the 2.5-lb weight plate was used in conjunction with the cross-training shoe, the combined functional heel lift was 20 mm (similar to the heel lift provided by AAW).

Figure 1. Footwear conditions used in the study. (a) Cross-training shoe. (b) Low PL (c) High PL. (d) Cross-training shoe with 2.5 lb. weight plate.

Barbell Back Squat Procedure

A one-repetition maximum (1RM) was determined using standard procedures and conversion charts (National Academy of Sports Medicine) before the experiment began. An instructional barbell back squat training video was shown to the subjects before any squatting was performed ("Technique Video: High-Bar Back Squat from the National Strength and Conditioning Association; video accessed during the 2014-15 academic year from (11). Subjects performed five sets of three squats at 75% of their 1RM; this weight was determined based on a consensus from previous similar studies (4,7,9,12). The first and fifth sets were performed in the cross-training shoes (AFT3) only as a control condition and to determine if fatigue became a factor across the squat series; the second through fourth sets consisted of AAW, AP2, or AFT3+weight plate in counterbalanced order). Subjects were instructed to squat until thighs were parallel to the floor. At parallel subjects held for a one-second count, upon which they would return back to the starting position. Subjects wore weightlifting gloves and a weightlifting belt during all exercise. A metronome was used to pace the repetitions with a five-second pause in between each repetition. Subjects were then given five minutes to rest in between sets. The squats were performed on force plates. Subjects placed their feet shoulder-width apart and the researchers then aligned both feet to ensure an even distribution of forefoot and rearfoot between the four plates. Tape marks on the shoes ensured that the shoes were positioned similarly on the force plates during all trials, both within and across subjects. The position of the tape marks was determined from a convenience sample of a small group of males who were near the lab when we were doing troubleshooting. It was determined that peak foot arch height occurred around 60% of the foot's length (i.e., force distribution would be radiating from that point), so tape marks were placed on the outsole of all shoe pairs at 60% of their length relative to the toe. Our findings were consistent with findings from digitized plantargrams obtained from a larger population of Americans (ref. Fig. 1 in (13)).

Ankle Goniometry

Goniometry was performed on the right ankles of the subjects to determine if any of the shoe models impacted baseline ankle range-of-motion (ROM) using four tests: dorsiflexion, plantarflexion, talar inversion, and talar eversion. Subjects were instructed to perform the movement to the most maximal extent possible while maintaining form appropriate to the movement. Subjects performed all four movements in the three shoe models plus a socks-only condition. A standard, plastic 12” goniometer capable of 360° movement (HPMS, Inc.) was used for the measurements. All measurements were taken at rest with the subject sitting on a table.

Knee Goniometry

Goniometry was also performed on the right knee of the subjects during the actual squat to determine subject squat depth. An electrogoniometer (Vernier Software & Technology, Beaverton, OR) was taped to each subject’s right leg. Electrogoniometry data was collected throughout all repetitions.

Force Plates

The experiment used four force plates (Vernier Software & Technology, Beaverton, OR) to determine forefoot and rearfoot force production throughout the entire exercise. One plate each was placed under the right forefoot, right rearfoot, left forefoot, and left rearfoot. Experimenters positioned each subjects’ feet prior to exercise so that the seam between two adjacent force plates (e.g., right forefoot and right rearfoot, and left forefoot and left rearfoot) occurred at foot peak arch height (Fig. 2; see also the “Barbell Back Squat Procedure” subsection above for rationale). Data collection started three seconds prior to the subjects beginning their first squat. Data collection ceased three seconds after the subject returned to the standing position following the third squat of each set. For the weight plate trials, a 2.5-lb weight plate was duct-taped to the rearfoot force plate to keep it stationary during the squat, and the force plates were zeroed to account for the the mass of the plates.

Figure 2. Foot placement for the back squat. Tape marks indicated the location of peak arch height, which was centered over the seam between two plates; thus, force distribution would be in either direction from the seam.

Perceptual Scales

Several psychological scales were taken for the subjects throughout the study. All psychological scales were obtained immediately following the squats while the subjects were still standing on the force plates. Comfort visual analogue scales (VAS), stability VAS, fatigue VAS, and RPE scales for exertion were the scales in the study. The RPE scale was based on the widely-used Borg model (14). The comfort VAS was a 10-cm continuum based on the generic model (15,16). The stability

VAS was a modification of the comfort VAS where comfort terms were replaced with stability terms, but was otherwise identical in construction and interpretation, and has been used previously by our team (17–20). Similarly, the fatigue VAS was a modification of the comfort VAS where comfort terms were replaced with fatigue terms; however, this VAS has not been previously employed by any team and was being explored as an alternative or companion to the Borg scale (which technically measures exertion and not fatigue, though the Borg scale is often used for fatigue).

Statistics

Statistics to analyze the data were performed on Statistical Package for the Social Sciences version 22 (IBM Inc.; Armonk, NY). Ankle goniometry statistics were analyzed using a one-way analysis of variance (ANOVA) with condition as the fixed variable. Psychological scales, knee goniometry, and force plate data were statistically analyzed using a two-way ANOVA with condition and trial order as the fixed variables. The fatigue VAS and Borg RPE scale were compared using a Pearson correlation. The analysis used $p < 0.05$ to determine statistical significance.

RESULTS

Ankle Goniometry

Ankle goniometry data is presented in Table 1. There were no significant differences between the four footwear conditions for any ankle movements.

Table 1. Ankle ROM values for dorsiflexion, plantarflexion, eversion, and inversion in four conditions. Values are expressed as means ± standard error.

	Dorsiflexion	Plantarflexion	Eversion	Inversion
Sock Only	12.6° ± 1.1°	45.2° ± 2.0°	11.9° ± 0.8°	24.2° ± 1.6°
Cross-Trainer	12.9° ± 1.0°	44.5° ± 1.3°	12.8° ± 1.0°	23.8° ± 1.2°
Low-end PL	12.3° ± 0.8°	43.0° ± 1.8°	10.7° ± 0.6°	23.6° ± 1.3°
High-end PL	12.2° ± 0.7°	42.5° ± 1.9°	12.1° ± 0.8°	23.2° ± 1.3°

Knee Goniometry

Knee goniometry data is presented in Table 2. There were no significant differences between the four footwear conditions for knee angle at any point during the squat.

Table 2. Knee angle data for the four footwear conditions at three points in the squat motion: before the squat, during the squat when holding, and after the squat.

	Before Squat	During Squat	After Squat
Cross-Trainer	180.3° ± 1.3°	76.5° ± 4.3°	181.2° ± 1.3°
Low-end PL	180.7° ± 1.6°	72.7° ± 3.3°	181.1° ± 1.6°
High-end PL	180.6° ± 1.5°	71.7° ± 3.2°	181.1° ± 1.5°
Weight Plate	179.2° ± 1.6°	71.6° ± 3.4°	180.4° ± 1.6°

Force Production

The force plate data showed significant differences between forefoot and rearfoot force production when comparing the four shoe conditions. However, all of these significant differences occurred before and after the squat when the subjects were standing upright. Significant differences in forefoot and rearfoot force production were not observed during the hold portion of the squat (Fig. 3).

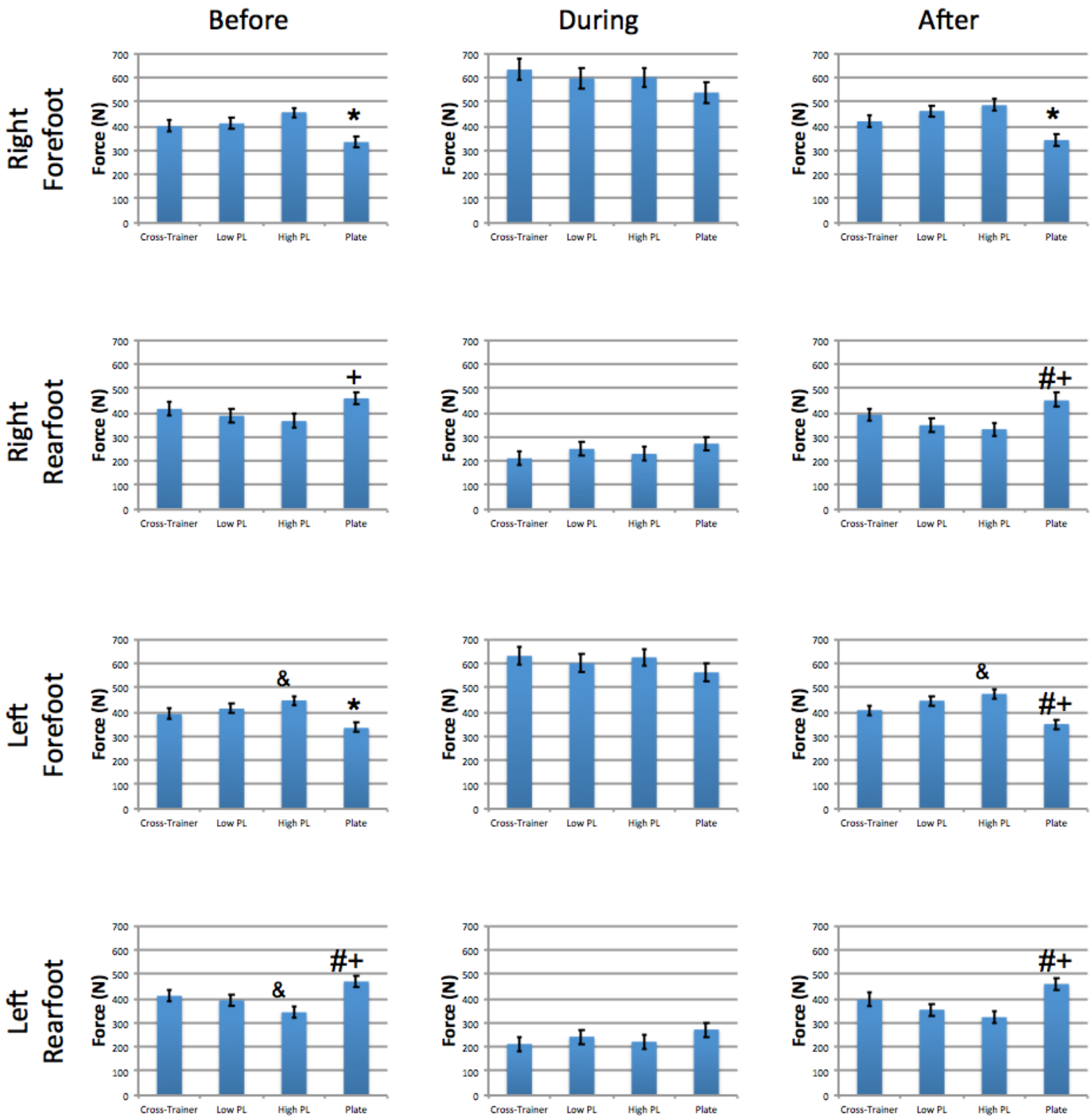

Figure 3. Symbols indicate significant differences ($p < 0.05$) as follows: * = plate versus all conditions ($p < 0.05$), + = plate versus high PL shoe only ($p \leq 0.05$), # = plate versus low PL shoe only ($p < 0.05$), & = high PL versus control only ($p < 0.05$). No significant differences were found between any of the shoe conditions for the hold portion of the squat.

Perceptual Outcomes

The perceptual data found no significant differences in comfort VAS, fatigue VAS, or RPE for any of the four footwear conditions. There were significant differences for perceived stability for the four footwear conditions (Fig. 4). The fatigue VAS and RPE scale were compared using a Pearson correlation (Fig. 5) which showed that there was a significant positive correlation ($p < 0.05$) between the two scales.

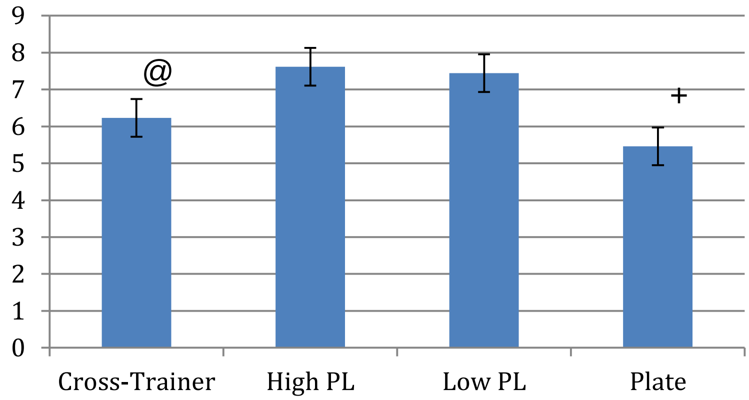

Figure 4. Subject's self-reported scores on visual analogue scales for stability. Symbols indicate significant differences as follows: @ = cross-trainer perceived as significantly less stable than the high PL ($p < 0.05$), + = weight plate perceived as significantly less stable than the low PL ($p < 0.05$).

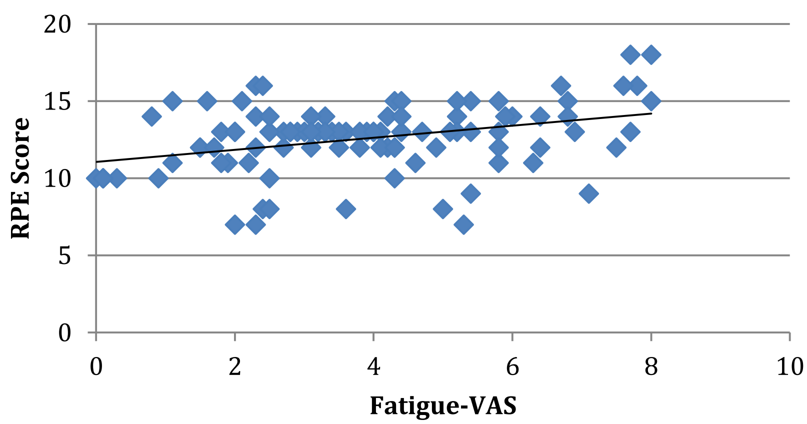

Figure 5. A significant positive correlation ($p < 0.05$) was found between fatigue VAS and the RPE scale. The Pearson's correlation coefficient was found to be 0.337.

DISCUSSION

It was hypothesized that placing a 2.5 lb. weight plate under the heel of a cross-training shoe would serve as an equally effective alternative to wearing powerlifting shoes during barbell back squats in terms of enhancing rearfoot force production. The data did not support this hypothesis.

Force plate results (Fig. 3) indicated that neither the powerlifting shoes nor the 2.5 lb. weight plate under the heel of the cross-trainer provided any significant benefits in terms of increasing rearfoot force production during the squat. These results countered expectations in that a previous study indicated powerlifting shoes promoted increased heel contact with the ground (12), which is consistent with proper technique (6). The significant differences between conditions before and after the squat do raise interesting questions. As force plate data was only able to be defined and collected before, during the hold, and after the squat motion, there are questions about what is occurring in terms of force production during the descend and ascend of the squat motion. Due to the equipment used for force production measurement, we were not able observe the descend and ascend portions.

Self-reported perceptual scales (Fig. 4) used to compare footwear conditions showed no significant differences in comfort VAS, fatigue VAS, and RPE. However, it was observed that subjects perceived the cross-training shoe with the weight plate to be significantly less stable than both the low-end powerlifting shoe ($p<0.05$) and the high-end powerlifting shoe ($p<0.05$). The cross-training shoe alone was also perceived as less stable than the high-end powerlifting shoe ($p<0.05$). The Pearson correlation performed allowed us to compare the frequently used Borg RPE scale to a newly created fatigue VAS (see Methods). To the best of our knowledge, this is the first study to use a fatigue VAS and therefore the first to be able to compare the fatigue VAS to the traditional Borg RPE. The Pearson correlation indicated a significant positive correlation between these scales measuring exertion and fatigue (Fig. 5; $p<0.05$). This significant value indicates the potential use of the fatigue VAS in conjunction with or in replacement of the Borg RPE scale, though more studies will be needed to determine if one might be used in lieu of the other.

The ankle goniometry results (Table 1) indicated that none of the footwear conditions had a significant effect on ankle ROM. This finding suggested that footwear condition would not likely influence ankle kinematics during squatting, which was important to investigate because if it was restricting any of the four measured motions, then it could have conceivably impacted the entire lower limb kinetic chain (from ankle through the back) during the squat; this in turn would have influenced the other measures in this study.

Knee goniometry results (Table 2) showed no differences between footwear conditions in regards to squat depth achieved. This finding was consistent with previous squat depth comparison made between powerlifting and cross-training shoes (12). Significant squat depth differences had been found between squatting in cross-training shoes and squatting barefoot (10), but the barefoot condition was not used in this study.

This study has some limitations. First, some of the variance in force production may be attributed to the heterogeneous nature of the participants. The subject pool consisted of participants with a variety of squat experience, as well as regular physical activity levels. Second, some of the variance in stability VAS scores may have been attributed to the surface of the force plates, which did not provide as much grip as a standard gym floor. Future research is needed to further analyze the effect of footwear conditions on force production. This research is original in that different powerlifting shoes have never been compared while performing barbell back squats. Different brands and types of powerlifting shoes could be compared in future research to discern whether certain shoes do provide significant benefits, particularly in terms of force production.

CONCLUSIONS

In conclusion, differing footwear conditions did not have a significant effect in altering rearfoot force production during the squat motion of barbell back squats. Some stability differences were observed but comfort, fatigue, and perceived exertion showed no difference between conditions. Barbell back squats require proper technique to gain lower extremity and torso strength and to prevent injury. Whether a particular type of footwear condition significantly promotes proper technique requires further research.

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