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Original Research Article

The Effects of Footwear on Force Production during Barbell Back Squats Part II: Standardizing Squat Depth

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Abstract

Introduction: Data concerning the advantages or disadvantages of using weightlifting shoes (compared to normal athletic or running shoes) for performing back squats has been largely equivocal. A recent review has suggested that a lack of standardization across studies has made it difficult to draw generalizations and may obscure any footwear effects. Therefore, the purpose of this study was to replicate the methods of a previously published study, except this time strictly controlling for squat depth. **Methods:** Eleven male college athletes (20 ± 1 yrs) performed back squats in three conditions: 1) weightlifting shoes, 2) running shoes, or 3) running shoes with an external heel elevation (which made them equivalent in heel elevation to the weightlifting shoes). Knee angles, forefoot force production, and rearfoot force production were measured during squats. Lifters' perceptions of shoe comfort and stability were measured after each condition. Static ankle goniometry was measured at rest for each condition as an internal "negative control". **Results:** No significant differences were found for any of the variables across any of the footwear conditions. **Conclusions:** These results are substantively similar to the aforementioned study that did not standardize squat depth, suggesting squat depth standardization may not have impacted the measured outcomes. Lifters' previous experience and set motor patterns may explain the results.

Key Words: Heel Contact, Heel Elevation, Powerlifting Shoes, Weightlifting Shoes.

Introduction

Barbell back squatting is a lifting technique that is used widely among individuals as it can enhance different muscles that flex and extend the hip and knee joints[1,2]. Correct technique is critical as lifting too heavy of a weight could result in an injury, lifting improperly could lead to skeletomuscular injuries, and lifting after a previous injury could increase the chances of re-injury[3,4]. While performing a barbell back squat, different footwear conditions (i.e., barefoot, raised platform under the heel, and a heel-raised weightlifting shoe) have been studied to determine the effects heel raising has on the activation of different lower extremity muscles. In theory, weightlifting shoes with their raised heel increase heel-with-ground contact[5,6] and provide better sole stability[7]. Whether or not a raised heel is advantageous is still somewhat debated—for example, one study showed that raising the heels increases knee extensor activity[8], another refuted that idea[4], and a third demonstrated greater heel height caused greater gastrocnemius (but not knee extensor) activation[9]. Effects from wearing a weightlifting shoe might vary by skill level[10]: for individuals who back squat regularly, wearing a weightlifting shoe might increase muscle activation, reduce forward trunk lean, or permit a deeper squat; whereas for novice back squatters, a weightlifting shoe might offset inflexibilities or reduce spinal torque[10] but could be prohibitively costly[11].

Studies comparing different footwear conditions for barbell back squats are limited, though most included a weightlifting shoe condition. As alluded earlier, some studies have shown no or irrelevant changes in form when wearing weightlifting shoes compared to athletic shoes[4,7,12]. Our laboratory previously showed that there were no differences in knee joint angles at the depth of the squat, nor in forefoot-rearfoot force distribution, when wearing weightlifting shoes compared to cross-trainers or cross-trainers with a weight plate positioned under the heel to replicate the heel elevation conferred by the weightlifting shoe[11]. In that study, subjects were told to squat until thighs were parallel with the ground, but not all subjects conformed to that request. By contrast, different researchers showed that weightlifting shoes reduced ankle flexion, increased knee flexion, reduced trunk lean, and increased the knee moment compared to standard athletic shoes, and may cause slightly different effects based on the lifter's experience[6,13]; however, it did not improve thigh positioning at parallel[6]. A recent review article asked the question, "Do specialty shoes boost weightlifting performance?" by performing a systematic review on barbell back squat studies ranging from the years of 2012 to 2017[14]. The ultimate take-away from the article was that more research needs to be conducted along with ensuring more standardization techniques (i.e., squat depth). This echoes the sentiment of other researchers in the field[15].

Although the review identified deficits that make cross-study comparisons difficult, those deficits also serve as signals to where additional experimental work needs to be done. As described in the preceding paragraph, Dorson[14] lamented the lack of standardized squat depth across studies. Our research team had conducted one[11] of the five main studies reviewed by Dorson. Putting everything together, we were curious if the results from the Schermoly *et al*. study[11] would have been different had we more strictly standardized squat depth, or if it would not have made any difference. To that end, the purpose of the current study was to repeat the Schermoly *et al*.

study[11] using the same protocol and same outcomes—only this time standardizing squat depth. Outcomes included foot force production and knee angles during the squat, and perceptual scores after the squat. Participants were asked to complete 3 sets of 3 repetitions in different footwear conditions (cross-trainer [control], cross trainer + heel elevation, and weightlifting shoe). We hypothesized that, across different footwear conditions, there would be no significant differences in (1) foot force production during the squat, (2) knee angles at the depth of the squat, or (3) post-squat perceptual scores for comfort, stability, or exertion.

Methods

Participants

This experiment was approved by the Drake University Institutional Review Board with the IRB ID being 2018-19008. Eleven males between the ages of 19 and 24 years provided written informed consent, and each of these males finished the experiment protocol completely. All eleven subjects had shoe sizes ranging from 10 to 13. Each subject was an active college athlete participating in a supervised weightlifting program and averaging 3 to 3.75 hours of strength and conditioning per week (including back squats). Most of the subjects were football players, but there were also athletes from golf, tennis, and throwing. All subjects came in between 11-11:50am. The characteristics of the subjects were (mean ± standard deviation): age = 20 ± 1 years, height = 179 ± 7 cm, weight = 82 ± 11 kg, and percent fat 13 ± 3.4 %. The load lifted during the squat was 234 ± 26 lbs.

Experimental Design

The subjects wore two separate types of shoes while completing the back squats (Figure 1): a cross-training shoe (Adidas Falcon Trainer 3), and a weightlifting shoe (Adidas powerlift.2). Per an earlier report[11], the cross-training shoe has a heel-to-toe drop of 4 mm whereas the weightlifting shoe has a heel-to-toe drop of 15 mm. Four shoe sizes were available (10, 11, 12, or 13), and subjects were fitted based on their normal shoe sizes.

Figure 1. The two shoes used in this experiment: the Adidas Falcon Trainer 3 (top) and the Adidas powerlift.2 (bottom). The front edge of each tape strip along the lateral outsole aligns with the foot arch peak.

Subjects performed back squats in three separate footwear conditions which were

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as follows: the cross-training shoe by itself (control), the weightlifting shoe, and the cross-training shoe with a 2.5 lb. weight plate that was put directly under the heel of the subject (Figure 2). The first trial was always the control trial and the other two trials were counterbalanced between the weightlifting shoe and the cross-training shoe with the weight plate underneath it. The 2.5 lb. weight plate used in this study had a width of 10mm. Thus, when the cross-training shoe had the 2.5 lb. weight plate underneath it, the combined heel-to-toe drop was approximately 14 mm, which is comparable to the native heel-to-toe drop of the weightlifting shoe.

Figure 2. Depiction of the cross-training shoe + plate condition with subject standing on the force plates. During the trials where the 2.5 lb. weight plate was used, the weight plate was duct-taped to the rearfoot force plate to ensure the plate was unable to move during the trials (not shown in this picture). This picture also shows how the electrogoniometer was attached to the right leg.

On each shoe there were tape marks that indicated peak foot arch height, as determined by the previous study to be around the 60% of the length of the foot as measured starting from the toe[11]. Thus, tape strips were attached to the outsole of the different footwear conditions at 60% of the foot's length relative to the subjects' toe. These tape marks were used to standardize subject's foot placement on the force plates.

Static angle goniometry was completed on all subjects' right ankles in order to determine if either of the shoes had an impact on the baseline levels of ankle range-of-motion (ROM); doing so was essentially an internal "negative control" to rule out any confounding effect of footwear condition on base ankle joint movement. Static goniometry was completed using four different tests which were as follows: dorsiflexion, plantarflexion, talar eversion, and talar inversion. Subjects were verbally instructed to complete the movements to the maximum degree possible while also making sure to maintain the movement's appropriate form. All subjects completed these tests in the two different shoe models along with a condition of socks only. The goniometer used was a standard, plastic 12" goniometer. This goniometer was also able to perform 360° movements (HPMS, Inc.). Ankle goniometry tests were completed while the subject was rested and sitting on a table.

Dynamic angle goniometry for the knee (Figure 2) was measured at the bottom of each squat in order to determine subjects' squat depth. An electrogoniometer (Vernier Software & Technology, Beaverton, OR) was placed on the lateral side of each subject's right knee and taped to the leg.

Procedures

Prior to the study, staff from the Drake University Strength & Conditioning coaching team determined each athletes' 1RM using conversion charts from the National Academy of Sports Medicine and standard procedures, completing squats to fatigue. Then separately, on the day of the study and before subjects performed any of their back squats, a training video was played showing the instructions on proper form[16].

Subjects performed three sets of three squats at 75% of their 1RM. The first set was always performed using the cross-training shoes. The second condition and third condition were counterbalanced. Half of the time, the second condition was the cross-trainer plus the weight plate and the third condition was the weightlifting shoe. Subjects were verbally directed to squat until thighs were parallel to the floor (as determined by an observer viewing them from the sagittal plane) while keeping their weight back on their heels; if subjects over- or undershot the appropriate thigh positioning, the attempt was discarded and the subject coached further before making another attempt. Two subjects were asked to come back for a second (repeat) session after looking at videos of their performance and our realizing their squat depth was not compliant with our standard. While at parallel, subjects held that position for a three-second count, after which they returned to the starting position. A metronome was utilized in order to pace each repetition while counting a five-second pause between each squat repetition. Velocity was not controlled during squatting. After a given set was complete, subjects then had a five-minute rest until beginning the next set. The data collection began after a researcher counted backwards from three – the subjects then began their squats. The data collection then stopped after the subject was in the upright position and had stabilized.

While performing the squats, the subjects stood on force plates (Vernier Software & Technology, Beaverton, OR) to differentiate between rearfoot and forefoot production throughout the entire experiment. One force plate was placed under the left forefoot, left rearfoot, right forefoot, and right rearfoot each. Each shoe had a tape mark indicating the peak arch of the foot (Figure 1); once the subject stood on the plates, researchers positioned their feet such that the tape marks aligned with the seam between the front and rear force plates (Figure 2). Force (N) was used to determine the foot force production values. Values were obtained by averaging 0.5 seconds of data while subjects were stationary in each respective position. Subjects were asked to stand still during the pre-squat phase, descend into the squat and hold the squat for 3 seconds, and once the post-squat was completed researchers waited for subjects to again come to a standstill before stopping data collection. The data was collected from the middle of the 3-second time period. The force plates were zeroed after each trial and after the weight plates were placed on the force plates in order to account for the mass of the weight plates.

Immediately after each set of squats, perceptual scales were shown to each subject while the subjects still stood on the force plates. Perceived comfort and stability were assessed with separate 10-cm visual analogue scales (VAS)[17,18]. Rating of perceived exertion (RPE) was assessed with the standard Borg scale[19].

Statistical analyses

Statistics to interpret the data were carried out on Statistical Package for the Social Sciences version 25 (IBM Inc.; Armonk, NY). The ankle static goniometry was analyzed statistically by performing a one-way analysis of variance, also known as an ANOVA. The fixed variable was the condition. The knee goniometry (electrogoniometry), force plate data, and psychological scales were analyzed statistically by using a two-way ANOVA with the fixed variables being the trial order along with the condition. Statistical significance was defined as $p<0.05$. All subsequent values are given as means ± standard error, to allow for comparisons to previous reports.

Results

Ankle goniometry data is shown in Table 1. There were no significant differences between the three footwear conditions for any measurement (all $p\geq0.373$).

Knee angles at the depth of the squat were not significantly different across the three conditions ($p=0.873$): cross-training shoe alone = 72.0° ± 3.6°, cross-training shoe + plate = 67.4° ± 3.2°, and weightlifting shoe alone = 68.1°± 10.7°.

Table 1. Ankle range-of-motion data for dorsiflexion, plantarflexion, talar inversion, and talar eversion for all shoe types (means ± standard error). There were no significant differences.

	Dorsiflexion	Plantarflexion	Eversion	Inversion
Sock Only	14.0° ± 0.9°	37.1° ± 1.8°	11.7° ± 0.8°	15.3° ± 1.0°
Cross Trainer	12.5° ± 1.0°	34.7° ± 1.7°	11.9° ± 1.1°	16.6° ± 1.5°
PLS	13.3°± 1.3°	34.2°± 1.6°	13.6°± 1.2°	17.3°± 1.5°

Force plate data is shown in Table 2. There were no significant differences between the three footwear conditions in rearfoot or forefoot force production before, after, or during the squat (all $p \geq 0.071$).

Table 2. Force plate data (expressed as means ± standard error) by footwear condition and squat phase. There were no significant differences for any comparison.

		Cross-Training Shoe Alone	Cross-Training Shoe + Plate	Weightlifting Shoe Alone
Left Front	**Before**	510 N ± 36.6	479 N ± 40.2	474 N ± 31.4
	During	637 N ± 31.7	620 N ± 37.5	553 N ± 40.4
	After	528 N ± 35.9	494 N ± 39.7	502 N ± 31.7
Left Rear	**Before**	446 N ± 36.1	492N ± 38.6	467 N ± 33.6
	During	306 N ± 19.8	342 N ± 25.7	402 N ± 23.9
	After	423 N ± 33.9	473 N ± 39.1	451 N ± 32.3
Right Front	**Before**	483 N ± 30.0	407 N ± 31.2	453 N ± 31.1
	During	641 N ± 25.1	585 N ± 27.6	577 N ± 36.9
	After	510 N ± 31.8	441 N ± 33.3	486 N ± 28.6
Right Rear	**Before**	413 N ± 33.2	472 N ± 35.8	467 N ± 35.4
	During	314 N ± 19.7	347 N ± 17.1	384 N ± 25.8
	After	390 N ± 34.9	442 N ± 36.7	425 N ± 32.4

Perceptual outcomes are shown in Table 3. There were no significant differences between the three footwear conditions for any perceptual outcomes (all $p \geq 0.079$).

Table 3. Perceptual scales for comfort, stability, and rating of perceived exertion (RPE) for the three different conditions (means ± standard error). There were no significant differences.

	Comfort	Stability	RPE
Cross Trainer Alone	5.76 cm ± 0.62	6.79 cm ± 0.60	12.3 cm ± 0.52
Cross Trainer + Weight Plate	5.95 cm ± 0.63	6.50 cm ± 0.71	12.3 cm ± 0.52
PLS	7.45 cm ± 0.52	8.22 cm ± 0.47	10.8 cm ± 0.66

Discussion

The purpose of this study was to repeat a previous experiment[11], only this time stringently standardizing the squat depth. It was hypothesized that there would not be a significant difference in results (in-squat knee angle goniometry, foot force production, or footwear perception) between the two studies. Data supported this hypothesis.

Ankle goniometry results (Table 1) indicated that there were no significant differences between the three footwear conditions for dorsiflexion, plantarflexion, talar inversion, and talar eversion. Ankle goniometry was important to measure because if any of the footwear conditions had limited ankle movement, this could have had an impact on the lower half of the body (i.e., knee and hip) when performing the back squat, which could also affect other measures that were taken in this study. Results from Table 1 are comparable to those reported previously from the Schermoly *et al*. study[11], where they also reported no significant differences for any of the four movements as a result of footwear condition (average values as follows: dorsiflexion = 12.5 ± 0.9°; plantarflexion = 43.8 ± 1.8°; talar eversion = 11.9 ± 0.8°; talar inversion = 23.7 ± 1.4°). Slight differences between the current study and the former study are expected given two different people performed the measurements.

Other studies have measured the effects of different footwear on foot angles *during* the squat. One team, using a weightlifting shoe nearly identical to ours and a running shoe of the same brand as ours, and standardizing squat depth, reported that foot dorsiflexion was increased when wearing the running shoe compared to the weightlifting shoe during the squat[15]. However, their running shoe had a heel elevation almost three times greater than our cross-training shoe (11 mm vs. 4 mm, respectively). Separately, another team using different makes and models of running and weightlifting shoes reported that foot segment angles (i.e., dorsiflexion) significantly increased when wearing a weightlifting shoe compared to a running shoe during the squat[6]; to our knowledge, squat depth was not standardized in this study. Due to technological constraints we did not measure foot joint angles during squatting.

Knee angles were not significantly different between the three footwear conditions in this study. That observation is comparable to what was reported previously in the Schermoly *et al*. study[11], where they likewise reported no significant differences in knee angle at the depth of the squat across footwear conditions (average values from the previous study were as follows: cross-training shoe alone = 76.5 ± 4.5°; cross-training shoe + plate = 71.6 ± 3.4°; weightlifting shoe alone= 71.7 ± 3.2°). Data obtained in this current study is also consistent with another research study that also used a weightlifting shoe while looking at knee angles during a barbell back squat[15]. Squat depth was also maintained within the knee goniometry data where subjects were told to squat to 90° each time. Squat depth was also shown to have a significant difference between performing a barbell back squat in a cross-training shoe along with performing it barefoot[12], but participants in this study did not perform a back squat barefoot. Another study[13] showed that weightlifting shoes showed an increased in knee flexion angles compared to shoes that were not used for weightlifting.

Force plate data (Table 2) indicated that there were no significant differences before, during, or after the back squat, in terms of rearfoot or forefoot force production, as a function of footwear condition (cross-training shoe alone vs. cross-training shoe + plate vs. weightlifting shoe alone). Results from Table 2 are both

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similar to and different from those of the Schermoly *et al*. study[11]. Both studies reported no significant differences in foot force production by shoe during the hold portion of the squat. However, the Schermoly *et al*. study reported several idiosyncratic differences in foot force production for specific combinations of conditions (footwear × force plate) either before or after the squat; given their inconsistent nature, it was unclear whether these differences were meaningful. In both the current study and the previous study, data was collected at discrete time points before the squat (pre-movement), during the squat, and after the squat (post-movement). It was difficult to pinpoint the forefoot and rearfoot force productions while the subjects were actively ascending and descending into the squats because of technological constraints, therefore data on the movements of the ascending and descending parts of the squat was not collected. It's possible that disparate findings between the two studies might be resolved if data could be collected during ascent/descent. Separately, the results in Table 2 aligned with those from a different study where there were no significant differences within the ground reaction forces of a raised heel versus a normal, flat heel[20].

Perceptual scales (Table 3) indicated that there were no significant differences of the three footwear conditions for comfort VAS, stability VAS, nor RPE. Results from Table 3 are comparable to the Schermoly *et al*. study[11] with one exception: the previous study reported the cross-training shoe was perceived as less stable than the weightlifting shoe. In this study and the previous study[11], all subjects wore identical brand-new socks (cotton crew socks; Body Glove, Inc.), so sock construction or fiber differences did not confound any outcomes. Separately, in another study of running versus weightlifting shoes, subjects rated the weightlifting shoe as less comfortable but more stable[15]. A study comparing weightlifting shoes, running shoes, minimalist shoes, and barefoot conditions reported that athletes preferred barefoot conditions over any type of shoe condition[12].

Overall, results from this study were substantively identical to a previous study from our lab that used the same methods but did not stringently control for squat depth[11]. This could be because squat depth does not impact on the variables we measured or, more likely, our subjects had performed enough back squats over the course of their lifetimes that their motor patterns were already engrained[7] and the footwear had only trifling impact on those patterns.

There were limitations to this study. First, there were two occasions within this study in which trials were repeated (i.e., subjects were asked to come back to the lab for a second go) due to technological and standardization discrepancies. Second, this study had a limited sample size, and they

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represented a variety of sports and thus likely differences in strength training program history. More participants would be needed in the future to allow for better resolution of statistical significances. Mixed-sex studies, and broader representation of athletes from different sports, might improve the generalizability of findings. Third, and related to that, we did not perform any direct statistical comparisons between the results of this current study and the former Schermoly *et al*. study[11] and the study in the present population included all NCAA athletes. Fourth, we did not measure hip or ankle angles during the squat, nor muscle activation patterns during the squat, and it is possible that the footwear conditions elicited differences in those variables that went undetected in this study. Neither was ascent or descent velocity controlled. Fifth, different weightlifting shoes might produce different results. Sixth, we did not formally survey what or how much experience the subjects had with weightlifting shoes prior to the study (though from casual conversation we got the impression that weightlifting shoes were novel to most if not all of the subjects). Cross-subject differences in previous experience with weightlifting shoes may have impacted the study results.

Conclusions

After controlling for squat depth across subjects (thighs parallel to the ground), we found no significant differences in knee angles, forefoot or rearfoot force production, or subjects' perceived comfort or stability scores during back squats in weightlifting shoes compared to standard training shoes or standard training shoes plus heel elevation. Although this study showed no significant impact of controlling for squat depth, Dorson's call[14] for greater consistency/standardization across studies is still relevant if we are to determine if weightlifting shoes in particular, or heel elevation more generally, have meaningful effects on back squat performance.

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References

1. van den Tillaar R, Andersen V, Saeterbakken A (2019). Comparison of muscle activation and kinematics during free-weight back squats with different loads. *PLoS ONE*, 14(5), e0217044.
2. Lorenzetti S, Gulay T, Stoop M, et al (2012). Comparison of the angles and corresponding moments in the knee and hip during restricted and unrestricted squats. *J Strength Cond Res*, 26(10), 2829-2836.
3. Case M, Knudson D, Downey D (2020). Barbell Squat Relative Strength as an Identifier for Lower Extremity Injury in Collegiate Athletes. *J Strength Cond Res,* 34(5), 1249-1253.
4. Lee S, Gillis C, Ibarra J, Oldroyd D, Zane R (2019). Heel-Raised Foot Posture Does Not Affect Trunk and Lower Extremity Biomechanics During a Barbell Back Squat in Recreational Weight lifters. *J Strength Cond Res*, 33(3), 606-614.

5. Comfort P, Kasim P (2007). Optimizing squat performance. *Strength Cond J*, 29(6), 10-13.
6. Sato K, Fortenbaugh D, Hydock DS (2012). Kinematic changes using weightlifting shoes on barbell back squat. *J Strength Cond Res*, 26(1), 28-33.
7. Southwell DJ, Petersen SA, Beach TA, Graham RB (2016). The effects of squatting footwear on three-dimensional lower limb and spine kinetics. *J Electromyogr Kinesiol*, 31, 111-118.
8. Kongsgaard M, Aagaard P, Roikjaer S, et al (2006). Decline eccentric squats increases patellar tendon loading compared to standard eccentric squats. *Clin Biomech*, 21(7), 748-754.
9. Johnston C, Hunt-Murray C, Hsieh C (2017). Effect of heel heights on lower extremity muscle activation for back-squat performance. In: *35th Conference of the International Society of Biomechanics in Sports*. Cologne, Germany.
10. Sayers MGL, Bachem C, Schütz P, et al (2020). The effect of elevating the heels on spinal kinematics and kinetics during the back squat in trained and novice weight trainers. *J Sports Sci*, 38(9), 1000-1009.
11. Schermoly TP, Hough IG, Senchina DS (2015). The Effects of Footwear on Force Production during Barbell Back Squats. *J Undergrad Kines Res*, 10(2), 42-51.
12. Sinclair J, McCarthy D, Bentley I, Hurst HT, Atkins S (2015). The influence of different footwear on 3-D kinematics and muscle activation during the barbell back squat in males. *Eur J Sport Sci*, 15(7), 583-590.
13. Legg HS, Glaister M, Cleather DJ, Goodwin JE (2017). The effect of weightlifting shoes on kinetics and kinematics of the back squat. *J Sports Sci*, 35(5), 508-515.
14. Dorson JR (2019). Do specialty shoes boost weightlifting performance? *Lower Extremity Rev*, 10(2), 53-56.
15. Whitting JW, Meir RA, Crowley-McHattan ZJ, Holding RC (2016). Influence of Footwear Type on Barbell Back Squat Using 50, 70, and 90% of One Repetition Maximum A Biomechanical Analysis. *J Strength Cond Res*, 30(4), 1085-1092.
16. National Strength and Conditioning Association (2015). Exercise Technique: High Bar Back Squat. Exercise Technique: High Bar Back Squat. https://www.nsca.com/education/videos/exercise-technique-high-bar-back-squat/
17. Mündermann A, Nigg BM, Stefanyshyn DJ, Humble RN (2002). Development of a reliable method to assess footwear comfort during running. *Gait & Posture*, 16(1), 38-45.
18. Mills K, Blanch P, Vicenzino B (2010). Identifying clinically meaningful tools for measuring comfort perception of footwear. *Med Sci Sports Exerc*, 42(10), 1966-1971.
19. Borg G (1970). Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*, 2(2), 92-98.
20. Wenning MR (2005). Kinematic and kinetic differences in the barbell squat wearing two different types of shoes. M.S. Thesis, Ball State University.