Heel-Raised Foot Posture and Weightlifting Shoes Do Not Affect Trunk and Lower Extremity Biomechanics during a Barbell Back Squat

Javier Ibarra  
*University of Nevada, Las Vegas, IBARRJ2@UNLV.NEVADA.EDU*

Derek Oldroyd  
*University of Nevada, Las Vegas, OLDROYD@UNLV.NEVADA.EDU*

Ryan Zane  
*University of Nevada, Las Vegas, ZANER1@UNLV.NEVADA.EDU*

Follow this and additional works at: [https://digitalscholarship.unlv.edu/thesesdissertations](https://digitalscholarship.unlv.edu/thesesdissertations)  
Part of the [Physical Therapy Commons](https://digitalscholarship.unlv.edu/physicaltherapy)

Repository Citation  
Ibarra, Javier; Oldroyd, Derek; and Zane, Ryan, "Heel-Raised Foot Posture and Weightlifting Shoes Do Not Affect Trunk and Lower Extremity Biomechanics during a Barbell Back Squat" (2016). *UNLV Theses, Dissertations, Professional Papers, and Capstones*. 3543.  
[https://digitalscholarship.unlv.edu/thesesdissertations/3543](https://digitalscholarship.unlv.edu/thesesdissertations/3543)
HEEL-RAISED FOOT POSTURE AND WEIGHTLIFTING SHOES DO NOT AFFECT TRUNK AND LOWER EXTREMITY BIOMECHANICS DURING A BARBELL BACK SQUAT

By

Javier Ibarra
Derek Oldroyd
Ryan Zane

A doctoral project submitted in partial fulfillment of the requirements for the

Doctor of Physical Therapy

Department of Physical Therapy
School of Allied Health Sciences
Division of Health Sciences
The Graduate College

University of Nevada, Las Vegas
May 2016
This doctoral project prepared by

Javier Ibarra

Derek Oldroyd

Ryan Zane

entitled

Heel-Raised Foot Posture and Weightlifting Shoes Do Not Affect Trunk and Lower Extremity Biomechanics during a Barbell Back Squat

is approved in partial fulfillment of the requirements for the degree of

Doctor of Physical Therapy
Department of Physical Therapy

Kai-Yu Ho, Ph.D.
Research Project Coordinator

Carrie Gillis, D.P.T.
Research Project Advisor

Merrill Landers, Ph.D.
Chair, Department of Physical Therapy

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Interim Dean
ABSTRACT

Background and Purpose: It is claimed that wearing weightlifting shoes with a raised-heel can improve posture and leg muscle activation, and reduce the risk of back injuries during a barbell back squat. However, these proclaimed biomechanical effects have not been thoroughly investigated. The purpose of this study was to compare the thoracic, lumbar, and lower extremity biomechanics during barbell back squat in 3 foot posture conditions.

Subjects: 14 healthy recreational weightlifters (7 male and 7 female) between the ages of 18-50 participated in the study. A minimum of 2 years weightlifting experience and regular training with the barbell back squat were required to participate in the study.

Methods: The study was conducted on two separate days. The participants' 1-RM (1 repetition maximum) was established during Day 1. Day 2 took place at least 24 hours after, in which participants performed barbell back squats in three different conditions (barefoot on a flat surface, barefoot on a raised-heel surface, and wearing raised-heel weightlifting shoes) at 80% of their 1-RM. The order of performing the lifts under the 3 different conditions was randomized. Surface Electromyography (EMG) used to assess the activation of the knee extensors (vastus lateralis) and paraspinal muscles at L3 and T12/L1 spinal levels. A 3D motion capture system and wireless electronic goniometer recorded the kinematics of the thoracic, lumbar spine, and knee during the squat movement to a depth where the hip is at least at the same level to the knee. A one-way repeated measures ANOVA was used to assess the effects of foot posture conditions on the biomechanical variables of interest.

Results: Results indicate that a raised-heel foot posture did not significantly affect trunk and lower extremity muscle activation [thoracic paraspinal (p=0.52), lumbar paraspinal (p=0.179), vastus lateralis (p=0.507)] or the trunk angles at terminal depth of the squat [thoracic spine (p=0.348), lumbar spine (p=0.283)].
Discussion: Our study demonstrates that foot posture does not significantly affect trunk and knee postures as well as the spinal and knee extensor muscle activations during the barbell back squat. Wearing raised-heel weightlifting shoes during the barbell back squat is unlikely to provide significant protection against back injuries for recreational weightlifters.
TABLE OF CONTENTS

Abstract ...................................................................................................................................... iii

List of Tables ............................................................................................................................... 1

List of Figures ............................................................................................................................... 2

Introduction .................................................................................................................................. 3

Methods ...................................................................................................................................... 5

Procedures .................................................................................................................................. 9

Data Analysis .............................................................................................................................. 13

Statistical Analysis ..................................................................................................................... 13

Results ....................................................................................................................................... 14

Discussion ................................................................................................................................. 17

Potential Limitations .................................................................................................................. 19

Appendix ..................................................................................................................................... 21

References .................................................................................................................................. 29

Curriculum Vitae ......................................................................................................................... 31
LIST OF TABLES

Table 1: Participant Demographics ........................................................................................................ 6

Table 2: Joint kinematics of the 3 conditions (Barefoot, Platform, WL Shoe) ................................. 15

Table 3: Muscle activation of the 3 conditions (Barefoot, Platform, WL Shoe) .............................. 15

Table 4: Proper technique of the squat exercise adapted from N.S.C.A. Position Paper ........ 28
LIST OF FIGURES

Figure 1A-C: Posterior, anterior, and side views of opto-reflective marker placement .......... 8
Figure 2: Raised-heel weightlifting shoe used in this study............................................. 8
Figure 3: Session 1 Participant Procedure........................................................................ 10
Figure 4: EMG placement on paraspinal muscles.............................................................. 10
Figure 5 A-C: Barefoot condition, platform condition, and shoe condition ..................... 12
Figure 6: Session 2 Participant Procedure........................................................................ 12
Figure 7: Joint kinematics of the 3 conditions (Barefoot, Platform, WL Shoe) ................. 16
Figure 8: Muscle activation at terminal depth of the 3 conditions (Barefoot, Platform, WL Shoe)........................................................................................................ 16
Figure 9: 1 RM Protocol; adapted by from NSCA “Essentials of Strength and Conditioning Ed. 3” ..................................................................................................................... 25
Figure 10: Warm-up Protocol adapted from Abad et al................................................... 26
INTRODUCTION

The barbell back squat is a weight bearing, compound movement that trains multiple muscle groups, and additionally develops balance and proprioception.1 As an exercise, it is ubiquitous across the spectrum of training programs implemented in strength and conditioning. With the growing popularity of strength training2,3, which the barbell back squat is one of the key exercises, the barbell back squat is routinely performed by competitive and recreational weightlifters. Given the popularity, numerous studies have investigated the prevalence of squat related injuries. A common finding among these studies is that the lower back is among the most common sites of injury during the barbell back squat.8, 9, 10 For example, a study by Siewe et. al found 40.8% of competitive powerlifters had experienced an injury to the lumbar spine, with the lumbar region a common site of pain during the barbell back squat.9

Footwear has long been discussed as a potential tool for injury prevention when performing the barbell back squat.16 Kilgore and Rippetoe reported that squatting in running shoes or cross trainers increase the risk of injury because their flexible soles provide an unstable surface and may produce aberrant motion under heavy load12. Thus, they argue the weightlifting shoe prevents squat related injury by providing a hard, non-compressible sole and a raised heel which allows the lifter to more reliably recreate the desired motor pattern while requiring less flexibility of the ankle than a flat or minimalist shoe.12 This is compatible with a study by Sato et al. which found that asymmetrical weight distribution between feet during the barbell back squat resulted in aberrant bar movements.13 Among the exercise populations that utilize barbell back squat, the use of footwear varies. For example, flat soled flexible shoes (i.e. Chuck Taylor sneakers or Reebok Power Shoe) are popular among powerlifters, while minimalist shoes (i.e. New Balance Minimus or Vibram FiveFingers), or Olympic weightlifting shoes (i.e Adidas Adipower or Nike Romaleo)
are also used. The Olympic weightlifting shoe differs from the other popular choices in that the Olympic weightlifting shoe features a prominent heel lift.

Current published research is limited in assessing the effects of different footwear on the biomechanics during execution of the barbell back squat. Sato et al. compared the kinematic changes of squatting in two different footwear conditions: Olympic weightlifting shoe vs. typical running shoes. The running shoes used in the study were categorized by the authors as “cushioning shoes”. They used a 2-D video analysis to measure the amount of relative displacement between the hip and the bar during squatting and found less trunk horizontal displacement in the weightlifting shoe with raised heel condition. This led to their conclusion that the use of an Olympic weightlifting shoe with a raised-heel may promote a more upright stance during the barbell back squat. The authors concluded that Olympic weightlifting shoes may aid those with back pain due to the decreased trunk displacement causing less strain on the lumbar spine. The authors also postulated that a more upright stance during the barbell back squat would reduce spinal extensor activation while increasing activity of the knee extensors during the movement although the muscle activations were not investigated in their study.

However, the previous study had a number of limitations. First, the 2-D method allowed limited tracking of movements of the trunk. In other words, their methods were unable to directly capture the segmental movement of the thoracic and lumbar spine segments. Second, the participants also performed the squat with non-standardized running shoes, which are variable by brand and may differ in stiffness. The effect of the raised-heel posture was not isolated from the effect of the shoe. Third, the weight the subjects lifted during the study was relatively low (60% of the subjects’ 1RM), which may not be representative of a typical effort for even recreational weightlifters.
To further explore the influence of foot posture on the biomechanics during squat, the purpose of this study was to compare the thoracic, lumbar, and lower extremity segmental kinematics and muscle activation during barbell back squat in 3 foot posture conditions (barefoot on a flat surface, barefoot on a raised-heel surface, and wearing raised-heel weightlifting shoes). We hypothesized that squatting with a raised-heel would promote a more upright trunk posture (i.e. reduced thoracic and lumbar flexion angle), leading to reduced muscle activation of the spinal extensors. Information gained from this research has implications for improving evidence-based exercise prescription and injury prevention recommendations in the field of strength and conditioning.

METHODS

Subjects:
14 healthy adults (7 female, 7 male) between 18-50 years of age (Table 1) participated in the study. Participants were required to have at least two years of weightlifting experience in addition to performing the barbell back squat at least once per month. Potential participants were excluded if they had any current symptoms that prevented them from performing heavy exertion, any musculoskeletal injury of the shoulder, back, and/or legs in the last three months, and any other conditions (cardiovascular, neurologic, and/or pregnancy) that prevented them from performing physical activity safely. An interview by one of the investigators and the administration of the Physical Activity Readiness Questionnaire and a Research Participation Screening Questionnaire were used to identify risk factors related to exercise exertion. The Screening Questionnaire included questions regarding: years of weightlifting experience and injury history.
Prior to participation, an investigator verbally explained the purpose and procedure of the study to potential participants. A copy of the informed consent approved by Institution Review Board for Biomedical Research at the University of Nevada, Las Vegas, was signed by the participant.

Table 1: Participant Demographics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Subject</td>
<td>14</td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
</tr>
<tr>
<td>Female</td>
<td>7</td>
</tr>
<tr>
<td>Age</td>
<td>26 ± 2.5</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.68 ± 0.11</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.72 ± 12.87</td>
</tr>
<tr>
<td>1 Rep Max (1RM)</td>
<td>196 ± 69 lbs.</td>
</tr>
<tr>
<td>Years of Strength Training</td>
<td>4 ± 1.52</td>
</tr>
<tr>
<td>Workouts per Week</td>
<td>3.43 ± 0.94</td>
</tr>
<tr>
<td>Minutes per Session</td>
<td>59.64 ± 12.78</td>
</tr>
</tbody>
</table>

Instrumentation

Consistent instrumentation was used to collect the biomechanical data. Three wireless EMG transceivers (Delsys Trigno Wireless System; Delsys, Inc., Natick, Massachusetts) were used to acquire neuromuscular activation signal of the right paraspinal and right knee extensor muscles. For the paraspinal muscles, the transceiver was placed at the L3 and T12-L1 levels, approximately 3-5 cm lateral to the spinous process on the muscle belly. For the knee extensor muscles, the transceiver was placed on the muscle belly of the vastus lateralis of the quadriceps muscle halfway between the anterior superior iliac spine (ASIS) and the lateral epicondyile of the femur. The surface of the skin was lightly abraded using #600 sandpaper, and cleaned with isopropyl ethanol alcohol. If needed, excessive hair on the skin was shaved to facilitate electrode fixation and electrical signal conduction. The EMG signals were sampled at 2000 Hz. Investigators used an isokinetic dynamometer, HUMAC NORM (CSMI Inc., Stoughton,
Massachusetts) to obtain the maximal voluntary isometric contraction (MVIC) of the spinal and knee extensors.

Opto-reflective markers were placed on the following anatomical landmarks: first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, the joint space between L4 and L5, and bilaterally over the greater trochanters, iliac crests, and anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), and acromion. In addition, clusters of rigid reflective tracking cluster markers were attached to neoprene bands secured bilaterally around the thigh, shank, heel counter, and the thoracic spine between T3 to T6 spinal levels (Figures 1A-C). The thoracic cluster allowed continuous tracking of the spinal kinematics during squat without interfering with the bar movement. Motion capture data were collected using the Vicon Nexus 2 system (Vicon Motion Systems, Ltd. Oxford, UK). The sampling frequency for the kinematic data was 200 Hz.

A declined platform was constructed of metal, 50 cm long (front-back), 100 cm wide (left-right), and at a decline angle of approximately 4.3 degrees. This angle was determined as it approximates the foot position when wearing a standardized size 10 weightlifting shoes with 3.3 cm of heel lift. The standing surface was lined with high friction material to provide traction during lifting. Standardized weightlifting shoes (VS Athletics, Torrance, California) were used with heel lift of 3.3 cm over the forefoot (Figure 2).
Figure 1A-C: Posterior, anterior, and side views of opto-reflective marker placement.

Figure 2: Raised-heel weightlifting shoe used in this study
A wireless spring electro-goniometer (Delsys Trigno Biaxial Goniometer Adapter; Delsys Inc., Natick, Massachusetts) was attached securely to the lumbar spine along the spinous process so that the center of the spring was over the L3 level to measure the segmental lumbar kinematics. The sampling frequency was 2000 Hz.

**Procedure**

Data collection was conducted in 2 sessions on separate days. On day 1, the participant established their 1 repetition maximum (1-RM) for the barbell back squat, in the barefoot condition. The 1-RM protocol utilized for this study is previously established (Figure 9). On day 2, the biomechanical assessment of the squat movement was conducted.

*Day 1:*

The 1-RM performance was established with the participant performing the lift from a standing posture, barefoot on firm rubber flooring. Each participant was required to reach a predetermined depth of squat that was consistent between each squat repetition. The accepted depth of squat was met when the participant’s hip (greater trochanter) reached the vertical level of the knee (lateral femoral condyle), forming a line that is parallel to the floor. The participant received verbal confirmation of appropriate depth from two investigators, standing on both sides in the sagittal plane. The instructions were provided to all participants in a uniform and consistent manner throughout this study. Participants were instructed to perform their individualized barbell back squat with a shoulder width and neutral foot position stance, and a high bar position. The high bar position was defined as bar contact over the spine of the scapula. Participants were allowed five seconds to perform one repetition with initiation of movement prompted by the investigator. A barbell rack with safety bars, and two spotters during the testing were used to ensure safety.
Figure 3: Session 1 Participant Procedure

Figure 4: EMG placement on paraspinal muscles.
Day 2:

The second testing session was conducted at least 24 hours after the first to avoid fatigue. EMG sensors were attached to the target muscles as described earlier, followed by 3 maximum voluntary isometric contraction (MVIC) trials of knee extension and back extension. The purpose of the MVIC trials were to obtain a reference 100% contraction level to normalize the EMG amplitude during squat. Knee extension was assessed at 60 degrees of knee flexion in a seated position and the trunk and the thigh are supported with straps. Resistance to knee extension was applied by an isokinetic dynamometer where the axis of the motor was aligned with the knee joint center. The back extension was conducted with the subject in a prone position. Straps were used to secure the pelvis, thigh, and with an investigator providing additional support to the calf. During the MVIC trials, the subjects were verbally encouraged to generate maximal contraction within 5 seconds. A rest period of 30-60 seconds was provided between trials. The highest muscle activation level over a 1-second duration was taken to establish the MVIC reference level.

After the MVIC trials, reflective markers and electrogoniometer were placed on the subject. A static calibration of the motion capture system was conducted. Subjects then performed standardized warm-up protocol adapted from Abad et al. (Figure 10).15

Subjects performed three barbell back squat movements in 3 different conditions (barefoot on a flat surface, barefoot on a raised-heel surface, and wearing raised-heel weightlifting shoes; Figure 5A-C). The squat trials were performed at 80% of their established 1-RM, with a rest period of at least one minute between trials. The order of the conditions was determined randomly for each subject.
Instructions consistent to Day 1, including foot positioning, squat depth, and pace, used during this phase of testing. All subjects were able to successfully complete the squat trials in all 3 conditions.

*Figure 5A: Barefoot condition. Figure 5B: Platform condition. Figure 5C: Shoe condition.*

*Figure 6: Session 2 Participant Procedure*
DATA ANALYSIS

The segmental kinematics were computed using Visual 3D Software (Qualisys Inc., Gothenburg, Sweden). The movement of the thoracic spine was defined as the relative movement between the marker cluster to the global coordinate system. Localized lumbar movement was quantified using based on data from the electro-goniometer. Knee range of motion was defined as the relative movement between the femur and tibia segments. Peak thoracic, lumbar, and knee joint angles during the squat movements were assessed. Additionally, the thoracic and lumbar angles at the instant of knee flexion were also assessed.

The EMG data was analyzed using a customized Matlab program (Mathworks, Inc., Natick, Massachusetts). The EMG data was band-pass filtered using a digital Butterworth filter (4th order, 10-350 Hz), then full-wave rectified. Mean muscle activation levels of the spinal and knee extensor muscles, were computed during the down-phase, up-phase, and at terminal depth of the squat. The down-phase was defined as when a subject descends between 20 degrees of knee flexion to peak knee flexion. The up-phase was defined as when a subject ascends between peak knee flexion to 20 degrees of knee flexion. The terminal depth was defined as the 1-second period when the peak knee flexion angle occurred (0.5 sec before to 0.5 sec after peak knee flexion). This time was determined so that the down-, up-, and terminal depth phases were similar in duration. The muscle activation magnitudes were then normalized to the highest 1-second average activation magnitude during the MVIC trials, and reported as percentages of the MVIC.

STATISTICAL ANALYSIS

To determine the influence of the 3 foot posture conditions on barbell squat performance, a one-way repeated measures ANOVA was conducted for each biomechanical variable of interest.
Biomechanical variables of interest included: 1) average amplitude of spinal and knee extensor EMG during the down-, up-, and terminal depth phases, and 2) peak joint angles of the thoracic, lumbar spine segments, and the knee joint. All statistical analysis was performed on SPSS 22.0 statistical software (International Business Machines Corp., Armonk, NY, USA) with a significance level of 0.05.

RESULTS
There were no significant differences in thoracic, lumbar and knee joint kinematic measures among the 3 foot posture conditions (Table 2). Although not statistically significant, a trend of difference in peak knee flexion (p=0.056) among the 3 conditions was detected. However, the difference between the platform condition and the barefoot level condition was on average only 2.5 degrees (platform vs. barefoot level, 128.2 ± 10.3° vs. 125.7 ± 11.8°). We observed no significant differences in thoracic, lumbar, and knee extensor muscle activation levels among the 3 foot posture conditions in any phases of the squat (Table 3).
Table 2: Joint kinematics of the 3 conditions (Barefoot, Platform, WL Shoe)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Barefoot</th>
<th>Platform</th>
<th>WL Shoe</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Knee Flexion</td>
<td>125.7 ± 11.8°</td>
<td>128.2 ± 10.3°</td>
<td>127.9 ± 10.2°</td>
<td>0.056</td>
</tr>
<tr>
<td>Thoracic Flexion at Peak Knee Flexion</td>
<td>38.5 ± 8.7°</td>
<td>37.1 ± 6.6°</td>
<td>37.2 ± 6.6°</td>
<td>0.348</td>
</tr>
<tr>
<td>Peak Thoracic Flexion</td>
<td>44.0 ± 7.4°</td>
<td>42.7 ± 5.4°</td>
<td>42.9 ± 6.8°</td>
<td>0.397</td>
</tr>
<tr>
<td>Lumbar Flexion at Peak Knee Flexion</td>
<td>25.6 ± 15.1°</td>
<td>26.7 ± 14.6°</td>
<td>26.1 ± 15.3°</td>
<td>0.283</td>
</tr>
<tr>
<td>Peak Lumbar Flexion Angle</td>
<td>26.9 ± 15.5°</td>
<td>27.8 ± 15.1°</td>
<td>27.3 ± 15.7°</td>
<td>0.290</td>
</tr>
</tbody>
</table>

Table 3: Muscle activation of the 3 conditions (Barefoot, Platform, WL Shoe)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Barefoot</th>
<th>Platform</th>
<th>WL Shoe</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean EMG Thoracic Down</td>
<td>0.34 ± 0.23</td>
<td>0.33 ± 0.23</td>
<td>0.33 ± 0.22</td>
<td>0.421</td>
</tr>
<tr>
<td>Mean EMG Thoracic Up</td>
<td>0.43 ± 0.31</td>
<td>0.43 ± 0.29</td>
<td>0.43 ± 0.28</td>
<td>0.821</td>
</tr>
<tr>
<td>Mean EMG Thoracic at Terminal Depth</td>
<td>0.46 ± 0.34</td>
<td>0.44 ± 0.30</td>
<td>0.44 ± 0.29</td>
<td>0.52</td>
</tr>
<tr>
<td>Mean EMG Lumbar Down</td>
<td>0.40 ± 0.27</td>
<td>0.36 ± 0.22</td>
<td>0.46 ± 0.46</td>
<td>0.299</td>
</tr>
<tr>
<td>Mean EMG Lumbar Up</td>
<td>0.52 ± 0.30</td>
<td>0.50 ± 0.26</td>
<td>0.52 ± 0.30</td>
<td>0.653</td>
</tr>
<tr>
<td>Mean EMG Lumbar at Terminal Depth</td>
<td>0.54 ± 0.34</td>
<td>0.50 ± 0.28</td>
<td>0.53 ± 0.33</td>
<td>0.179</td>
</tr>
<tr>
<td>Mean EMG Quad Down</td>
<td>0.69 ± 0.20</td>
<td>0.67 ± 0.20</td>
<td>0.69 ± 0.18</td>
<td>0.3</td>
</tr>
<tr>
<td>Mean EMG Quad Up</td>
<td>1.09 ± 0.29</td>
<td>1.06 ± 0.28</td>
<td>1.09 ± 0.30</td>
<td>0.459</td>
</tr>
<tr>
<td>Mean EMG Quad at Terminal Depth</td>
<td>0.96 ± 0.30</td>
<td>0.93 ± 0.31</td>
<td>0.96 ± 0.29</td>
<td>0.507</td>
</tr>
</tbody>
</table>
Figure 7: Joint kinematics of the 3 conditions (Barefoot, Platform, WL Shoe)

Figure 8: Muscle activation at terminal depth of the 3 conditions (Barefoot, Platform, WL Shoe)
DISCUSSION

With the current popularity of the barbell back squat in competitive and recreational athletics, there has been debate about the use of footwear for injury prevention. There is an ongoing discussion regarding whether performing squat in a heel-raised position can provide meaningful protection against lower back injuries.\(^6\) The current study is the first to comprehensively examine the kinematics of trunk as well as the muscle activation levels of the paraspinal and knee extensor muscles during squat. Our results showed that the raised-heel foot posture, achieved either by an angled platform or specialized weightlifting shoes, did not significantly influence the spinal posture and activation of the selected muscles during squat movement in recreational weightlifters.

Using the raised-heel footwear to prevent back injuries during the squat is based on the theory that a more upright posture can be achieved. Utilized as an exercise to develop leg muscle strength, such upright posture has been suggested to lead to greater knee extensor muscle activation and reduced spinal load. For example, Schoenfeld et al. postulated that the rectus femoris has a greater force/length advantage during a squat when the trunk is in a more erect position and that lumbar forces are decreased in this posture.\(^7\) While an increase in knee extensor muscle activation would promote improved quad recruitment and overall increase strength of the knee extensors, a decrease in paraspinal muscle activity may be indicative of decreased stress to the spine during the barbell back squat. Hence, an upright trunk posture during barbell squat was theorized to be more effective for building leg strength and preventing spinal injuries. The use of raised-heel footwear was promoted as a simple method to achieve the more upright posture.

Under this premise, Sato et al. examined the differences in squat kinematics between wearing a running shoe and a weightlifting shoe.\(^6\) Using a 2D method, the authors determined that the use of
weightlifting shoes during the barbell back squat led to increased foot segment plantarflexion angle and reduced trunk lean measured as reduced horizontal displacement between the hip and the center of the bar. Our results disagreed with results from this previous study. Among the 3 foot posture conditions, we did not observe statistically significant differences in thoracic and lumbar flexion angles as well as the peak knee flexion angle. This discrepancy between our findings likely stemmed from the difference in the respective experimental methods. First, the 2-D method employed by Sato et al. allowed limited tracking of movements of the bar and the hip. The 2D method was unable to directly capture the angular displacements of the thoracic and lumbar spine segments. Without specifically measuring segmental kinematics, it was not possible to discern the source of the observed kinematic differences. Also, the reported difference of 20 mm of horizontal displacement may be due to a subtle change in the placement of the bar between conditions. In contrast, we examined the thoracic and lumbar angles independently using a more direct method that allowed us to track the motions of the segments. In addition, the control condition in our study was squatting barefooted as compared to wearing subject’s own running shoes, which may differ in brands and stiffness. By controlling these factors, the methodology of the current study may have allowed more consistent kinematic measurements.

Although we did not observe any significant differences in thoracic, lumbar, and knee kinematics among the 3 foot posture condition, we observed a trend of greater peak knee flexion in the 2 raised-heel postures when compared to the barefoot level condition. While the difference is very small (2.2 to 2.5°), this may be indicative that the subjects were able to squat slightly lower with raised-heels. The greater knee flexion with the platform and shoe may be attributed to lack of ankle dorsiflexion in certain subjects. By performing the barbell back squat with a heel raise, the subjects can achieve greater depth before experiencing limiting dorsiflexion range of motion at the ankle. This result is in agreement with the hypothesis that the heel-raised posture during a
barbell back squat promotes an increase in knee flexion.\textsuperscript{7,17} However, this effect may only benefit those who have limited ankle dorsiflexion range of motion or weightlifters attempting to perform squats to a depth much greater than in the current study.

While the results of this study indicate that weightlifting shoes may not be effective in prevention of low back injury, there may be implications for positive influence in weightlifting performance. Many weightlifters choose to train in weightlifting shoes in order to lift heavier weights; injury prevention may not be the primary driving factor in the choice to wear weightlifting shoes. The trend in peak knee flexion could have implications for competitive weightlifters who regularly train the back squat beyond a parallel depth. The ability to train at an increased squat depth may positively affect performance due to training through an increased range of motion.\textsuperscript{19}

Our results suggest that weightlifting shoes with a raised heel do not induce appreciable biomechanical changes in the kinematics and muscle activation of thoracic and lumbar spine, as well as the knee joint when performing the barbell back squat in the recreational weightlifting population. The results of our study illustrated that the protective quality of footwear against lower back injury during the barbell back squat is negligible in recreational weight lifters. For preventing back injuries during squat, it is perhaps more important to stress proper technique and a safe progression of resistance (Table 4).\textsuperscript{18} Future research should focus on the performance benefits of the raised-heel posture in specific high performance weightlifting populations.

\textbf{Potential Limitations}

Possible limitations that have been taken into consideration include squat technique, weightlifting experience, apprehension related to location/setting, anthropometrics difference and practice effects. Some participants may favor an Olympic stance, while others may favor a wide
powerlifting stance during the barbell back squat. These techniques may alter muscle activation. Various levels of weightlifting experience may alter the overall muscle activation secondary to muscle efficiency. Participants may have underperformed due to the unfamiliarity of weightlifting conditions, the majority of participants stated they have never performed the back squat barefoot, or in a weightlifting shoe.
APPENDIX
LIST OF FIGURES

Figure 1A-C: Posterior, anterior, and side views of opto-reflective marker placement.

Figure 2: Raised-heel weightlifting shoe used in this study
Figure 3: Session 1 Participant Procedure

Figure 4: EMG placement on paraspinal muscles.
Warm-up Protocol

Instrumentation

Conditions (Randomized)
- Barefoot
- Barefoot w/ slant
- WL Shoe

Debrief

Figure 5A: Barefoot condition.  
Figure 5B: Platform condition.  
Figure 5C: Shoe condition.

Figure 6: Session 2 Participant Procedure
**Kinematics**

![Kinematics Diagram](image)

*Figure 7: Joint kinematics of the 3 conditions (Barefoot, Platform, WL Shoe)*

**Muscle Activation at Terminal Depth**

![Muscle Activation Diagram](image)

*Figure 8: Muscle activation at terminal depth of the 3 conditions (Barefoot, Platform, WL Shoe)*
Figure 9: 1 RM Protocol; adapted by from NSCA “Essentials of Strength and Conditioning Ed. 3”

1. Subject squats with light resistance that easily allows for 10 repetitions
2. Subject rests 1 minute.
3. Subject squats with load estimated to allow for 3-5 repetitions by adding 30-40 pounds (14-18kg)
4. Subject rests 2 minutes
5. Conservative, near maximal load is estimated that will allow subject to squat 2 to 3 repetitions by adding 30-40 pounds (14-18kg).
6. Subject rests for 2 to 4 minutes.
7. Make a load increase of 30 to 40 pounds (14-18kg).
8. Instruct subject to attempt 1RM.
9. If subject was successful in attempt, have subject rest 2-4 minutes, increase load and instruct subject to attempt 1RM
10. Repeat until subject reaches 1RM.
11. If unsuccessful in step 7, decrease load by 15-20 pounds and repeat step 8.
Figure 10: Warm-up Protocol adapted from Abad et al.

1. Perform a set of 8 repetitions with 50% of 1RM

2. Subject rests 2 minutes

3. Perform a set of 3 repetitions with 70% of 1RM

4. Subject rests 3 minutes

5. Subject performs 1 repetition with 80% of 1RM (under one of three conditions)
### List of Tables

#### Table 1: Participant Demographics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Subject</td>
<td>14</td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
</tr>
<tr>
<td>Female</td>
<td>7</td>
</tr>
<tr>
<td>Age</td>
<td>26 ± 2.5</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.68 ± 0.11</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.72 ± 12.87</td>
</tr>
<tr>
<td>1 Rep Max (1RM)</td>
<td>196 ± 69 lbs.</td>
</tr>
<tr>
<td>Years of Strength Training</td>
<td>4 ± 1.52</td>
</tr>
<tr>
<td>Workouts per Week</td>
<td>3.43 ± 0.94</td>
</tr>
<tr>
<td>Minutes per Session</td>
<td>59.64 ± 12.78</td>
</tr>
</tbody>
</table>

#### Table 2: Joint kinematics of the 3 conditions (Barefoot, Platform, WL Shoe)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Barefoot</th>
<th>Platform</th>
<th>WL Shoe</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Knee Flexion</td>
<td>125.65 ± 11.75</td>
<td>128.17 ± 10.29</td>
<td>127.89 ± 10.16</td>
<td>0.056</td>
</tr>
<tr>
<td>Thoracic Flexion at Peak Knee Flexion</td>
<td>38.47 ± 8.66</td>
<td>37.08 ± 6.55</td>
<td>37.16 ± 6.63</td>
<td>0.348</td>
</tr>
<tr>
<td>Peak Thoracic Flexion</td>
<td>44.03 ± 7.42</td>
<td>42.67 ± 5.35</td>
<td>42.89 ± 6.82</td>
<td>0.397</td>
</tr>
<tr>
<td>Lumbar Elgon Angle at Peak Knee Flexion</td>
<td>25.55 ± 15.07</td>
<td>26.65 ± 14.58</td>
<td>26.05 ± 15.29</td>
<td>0.283</td>
</tr>
<tr>
<td>Lumbar Elgon Angle Max</td>
<td>26.88 ± 15.52</td>
<td>27.82 ± 15.10</td>
<td>27.31 ± 15.69</td>
<td>0.29</td>
</tr>
</tbody>
</table>

#### Table 3: Muscle activation of the 3 conditions (Barefoot, Platform, WL Shoe)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Barefoot</th>
<th>Platform</th>
<th>WL Shoe</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean EMG Thoracic Down</td>
<td>0.34 ± 0.23</td>
<td>0.33 ± 0.23</td>
<td>0.33 ± 0.22</td>
<td>0.421</td>
</tr>
<tr>
<td>Mean EMG Thoracic Up</td>
<td>0.43 ± 0.31</td>
<td>0.43 ± 0.29</td>
<td>0.43 ± 0.28</td>
<td>0.821</td>
</tr>
<tr>
<td>Mean EMG Thoracic at Terminal Depth</td>
<td>0.46 ± 0.34</td>
<td>0.44 ± 0.30</td>
<td>0.44 ± 0.29</td>
<td>0.52</td>
</tr>
<tr>
<td>Mean EMG Lumbar Down</td>
<td>0.40 ± 0.27</td>
<td>0.36 ± 0.22</td>
<td>0.46 ± 0.46</td>
<td>0.299</td>
</tr>
<tr>
<td>Mean EMG Lumbar Up</td>
<td>0.52 ± 0.30</td>
<td>0.50 ± 0.26</td>
<td>0.52 ± 0.30</td>
<td>0.653</td>
</tr>
<tr>
<td>Mean EMG Lumbar at Terminal Depth</td>
<td>0.54 ± 0.34</td>
<td>0.50 ± 0.28</td>
<td>0.53 ± 0.33</td>
<td>0.179</td>
</tr>
<tr>
<td>Mean EMG Quad Down</td>
<td>0.69 ± 0.20</td>
<td>0.67 ± 0.20</td>
<td>0.69 ± 0.18</td>
<td>0.3</td>
</tr>
<tr>
<td>Mean EMG Quad Up</td>
<td>1.09 ± 0.29</td>
<td>1.06 ± 0.28</td>
<td>1.09 ± 0.30</td>
<td>0.459</td>
</tr>
<tr>
<td>Mean EMG Quad at Terminal Depth</td>
<td>0.96 ± 0.30</td>
<td>0.93 ± 0.31</td>
<td>0.96 ± 0.29</td>
<td>0.507</td>
</tr>
</tbody>
</table>
Table 4: Proper technique of the squat exercise adapted from N.S.C.A. Position Paper

<table>
<thead>
<tr>
<th><strong>Proper Form in the Squat Exercise</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Use approximately a shoulder-width foot stance.</td>
</tr>
<tr>
<td>Descend in a controlled manner. Ascent can be made at a variety of speeds. At faster speeds there should be no compromise in technique.</td>
</tr>
<tr>
<td>Proper breath control is important to support the torso. The breath should be held from the start of the descent until the athlete passes the sticking point on the ascent.</td>
</tr>
<tr>
<td>Avoid bouncing or twisting from the bottom position.</td>
</tr>
<tr>
<td>Maintain a normal lordotic posture with the torso as close to vertical as possible during the entire lift.</td>
</tr>
<tr>
<td>Feet should be kept flat on the floor.</td>
</tr>
<tr>
<td>Forward lean of the knee increases shear forces on the knee. Keeping the shin perpendicular may increase shear forces on the back as a result of forward trunk inclination. Although there are few exceptions, the shin generally should remain as vertical as possible to reduce shear forces at the knee. Maximal forward movement of the knees should place them no more than slightly in front of the toes. Depending on the type of squat being used, volume and intensity should not be increased at a rate that exceeds the body’s ability to adapt to the imposed demands.</td>
</tr>
<tr>
<td>Every effort should be made to maintain a consistent stable pattern of motion for each repetition, in order to load the muscles in a consistent manner and help prevent injury.</td>
</tr>
</tbody>
</table>
REFERENCES


Javier J. Ibarra, SPT, CSCS

EDUCATION

DPT  Doctor of Physical Therapy  
University of Nevada, Las Vegas, May 2016

BA  History  
University of California, Los Angeles, June 2007

CLINICAL EXPERIENCE

Henderson Physical Therapy  
Henderson, NV January 2016- April 2016

St Rose Dominican Hospitals – De Lima Campus  
Henderson, NV November 2015- December 2015

Desert View Hospital  
Pahrump, NV October 2015- November 2015

Cleveland Clinic Lou Ruvo Center for Brain Health  
Las Vegas, NV July 2015- September 2015

Rehab Services of Nevada  
Las Vegas, NV June 2014- August 2014

EMPLOYMENT EXPERIENCE

University of Nevada, Las Vegas, NV, August 2014- May 2015  
Graduate Assistant of Neuroscience, Department of Physical Therapy

RESEARCH IN PROGRESS

Lee SP, Gillis C, Ibarra J, Oldroyd D, Zane R. Heel-Raised Foot Posture and Weightlifting Shoes Do Not Affect Trunk and Lower Extremity Biomechanics During a Barbell Back Squat

PROFESSIONAL MEMBERSHIP/CERTIFICATIONS

American Physical Therapy Association Member since June 2013  
CPR and AED Certified since April 2014  
Certified Strength and Conditioning Specialist (NSCA) since November 2015

SUPPLEMENTAL EDUCATION

Combined Sections Meeting of APTA; 2014 Las Vegas, NV
EDUCATION

DPT  Doctor of Physical Therapy  
University of Nevada, Las Vegas, May 2016

B.S.  Human Movement Science; Pre-Physical Therapy  
Utah State University, Logan, May 2013

CLINICAL EXPERIENCE

Comprehensive Physical Therapy  
Henderson, NV January 2016- April 2016

St Rose Dominican Hospitals – Siena Campus  
Henderson, NV October 2015- December 2015

Health South Rehabilitation Hospital  
Las Vegas, NV July 2015- September 2015

Boulder City Hospital Outpatient Clinic  
Las Vegas, NV June 2014- August 2014

RESEARCH IN PROGRESS

Lee SP, Gillis C, Ibarra J, Oldroyd D, Zane R. Heel-Raised Foot Posture and Weightlifting Shoes Do Not Affect Trunk and Lower Extremity Biomechanics During a Barbell Back Squat

PROFESSIONAL MEMBERSHIP/CERTIFICATIONS

American Physical Therapy Association Member since June 2013  
CPR and AED Certified since April 2014

SUPPLEMENTAL EDUCATION

Combined Sections Meeting of APTA; 2014 Las Vegas, NV
Ryan S.C.S.K. Zane, SPT, CSCS

EDUCATION

DPT  Doctor of Physical Therapy
     University of Nevada, Las Vegas, May 2016

B.S.  Biology
     Psychology
     Washington State University, May 2013

CLINICAL EXPERIENCE

Tim Soder Physical Therapy – Southwest Clinic
     Las Vegas, NV January 2016- April 2016

St Rose Dominican Hospital – San Martin Campus
     Las Vegas, NV October 2015- December 2015

Rehabilitation Hospital of the Pacific
     Honolulu, HI July 2015- September 2015

Mike O’Callahan Federal Hospital
     Las Vegas, NV June 2014- August 2014

RESEARCH IN PROGRESS

Lee SP, Gillis C, Ibarra J, Oldroyd D, Zane R. Heel-Raised Foot Posture and Weightlifting Shoes Do Not Affect Trunk and Lower Extremity Biomechanics During a Barbell Back Squat

PROFESSIONAL MEMBERSHIP/CERTIFICATIONS

Certified Strength and Conditioning Specialist (CSCS) 2015-2016
National Strength and Conditioning Association (NSCA) 2014-2016
American Physical Therapy Association (APTA) 2013-2016
Nevada Physical Therapy Association 2013-2016
USA Weightlifting Level 1 Coach 2013-2016
Healthcare Provider CPR and AED Certification 2009-2016

SUPPLEMENTAL EDUCATION

Combined Sections Meeting of APTA; 2016 Anaheim, CA
National Student Conclave of APTA; 2014 Milwaukee, WI
Combined Sections Meeting of APTA; 2014 Las Vegas, NV