

## The impact of weightlifting shoes on performance and injury prevention in competitive weightlifting

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Received: 13 July 2024; accepted: 26 February 2025

Weightlifting shoes have played a crucial role in enhancing the performance and safety of athletes in sports such as Olympic weightlifting and powerlifting. This review paper has explored the impact of weightlifting shoes on the kinetics and kinematics of weightlifting movements. A comprehensive literature review has revealed that weightlifting shoes significantly alter the mechanics involved in squats, snatches, and clean and jerks. The use of weightlifting shoes has been shown to benefit experienced athletes by boosting their performance, however, further studies have been recommended for beginner and intermediate-level athletes to understand the full potential of these shoes. This review has provided valuable insights into the benefits and considerations of incorporating weightlifting shoes in training and competitions, highlighting the need for tailored research to optimize athletic performance.

**Keywords:** EMG analysis, Kinematics, Kinetics, Olympic weightlifting, Powerlifting, Squat, Weightlifting

### 1 Introduction

The modern form of weightlifting in the Olympics was introduced in 1896, marking the beginning of a competitive sport that challenged athletes to set higher weight records in each competition<sup>1</sup>. Originally known as "triathlon," the sport included three individual lifts: the clean and press, the snatch, and the clean and jerk. Over time, weightlifting evolved to focus on two individual lifts: the snatch and the clean and jerk. As the sport progressed, so did the design of weightlifting shoes (WLS)<sup>2</sup>.

The engineering and design of weightlifting shoes advanced significantly, with notable contributions from the Soviet design, which introduced a high top and raised heel of 2.5 cm or higher, nailed to the bottom of the shoe<sup>3</sup>. This innovation inspired Adidas to collaborate with legendary weightlifter Tommy Kono to develop the first modern weightlifting shoe<sup>4</sup>. Subsequently, Adidas refined and altered their WLS models every four years in preparation for major competitions such as the Olympics. Other brands like Nike, Reebok, and Nobull also began producing their own WLS with varying materials and design features to optimize lifting performance for athletes.

The introduction of the squat style in the 1940s and early 1950s revolutionized WLS design by enabling

athletes to lift heavier weights. This squat style gained attention across different sports and exercises within those sports<sup>10</sup>. For example, weightlifters use squats to increase quadriceps strength and overall lower extremity strength<sup>11</sup>. Studies have also demonstrated that increasing stance width and hip rotation can activate adductor and gluteus maximus muscles<sup>12</sup>. Squats are also essential for athletes in sports like rugby, football, and basketball to develop leg musculature and improve performance in their respective activities<sup>13</sup>.

Powerlifting, which includes lifts like the bench press, deadlift, and squats, emphasizes the importance of squats for muscle building and power development<sup>14-17</sup>. The barbell back squat is particularly effective for lower extremity muscle strength<sup>18</sup>. The recommended kinematics for squats emphasizes maintaining proper knee alignment and trunk position<sup>19,20</sup>.

The problem with the full squat is full squats may cause stretching of medial and lateral ligaments at the knee joint, resulting in decreased stability of the knee<sup>21</sup>. In Olympic weightlifting and powerlifting, high bar squats are widely recommended. The variations include partial squats, half squats, and full squats<sup>22</sup>. While full squats are recommended for Olympic weightlifting training and competitions, half squats are preferred for powerlifting due to potential injury risks associated with deep squats<sup>23</sup>. The International Weightlifting Federation mandates the use

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of WLS to ensure athlete safety and stability during competitions<sup>24</sup>.

There are speculations about the potential risks of barbell back squats to knees or lower back. However, the American College of Sports Medicine has clarified that when performed properly, barbell back squats are not inherently harmful. Injuries may result from improper form or excessive training volume<sup>25</sup>.

Research comparing WLS with other footwear conditions such as barefoot, running shoes, minimalistic shoes, and cross-training shoes has explored their kinematic and kinetic behavior using electromyography (EMG) analysis and center of pressure (COP) analysis. While WLS are widely recommended for weightlifting movements, their specific role in preventing imbalances and providing lift support requires further exploration<sup>26-30</sup>.

This review was prompted by best-practice interventions and contemporary research on the subject. The study aims to identify factors influencing the recommendation of WLS for athletes and to identify any necessary interventions for future studies. The guiding question for this integrative review is: "What is the impact of using WLS on individuals performing Olympic weightlifting or any form of squats or regular exercise involving squats?"

## 2 Materials and Methods

### 2.1 Protocol

The method for conducting this systematic review is written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines<sup>31</sup>.

### 2.2 Selection and eligibility criteria

The articles are collected from the internet databases using the following keywords and their combinations: EMG analysis, kinetics, kinematics, olympic weightlifting, powerlifting, squat and weightlifting in English with the exact term and associated descriptors. The article search is carried out in 3 popular academic database search engines by gathering all the research papers which come under these keywords. There are certain inclusion criteria for the author to include certain type of study and to exclude certain type of study. The review consists of articles which compare the WLS with other types of footwear conditions such as barefoot condition, running shoe, minimalistic shoe and cross training shoe. The studies that involve these shoes which study their kinematic and kinetic behavior which also

includes their EMG analysis and COP analysis are included in these studies. Abstract only studies are excluded and also the studies which were not in english language are excluded. Studies which doesn't involve either the WLS or the kinematic and kinetic behavioral studies are excluded. Other kinds of sports related studies has been excluded.

### 2.3 Information sources

The database from which the search is carried out from march to June 2022 were Pubmed, Google scholar and Science direct (Fig. 1). The review strategy is carried out in a systematic and orderly manner, contributing to the complete understanding of the subject to be studied. It involved in gathering the studies by using the keywords against these databases and collecting the relevant studies which has been published in this area. A title and summary analysis are performed to confirm the inclusion within the inclusion criteria and later, the collection is organized, analyzed and interpreted according to match the theme of this review paper.

### 2.4 Result analysis

The findings are given in a descriptive manner, allowing the reader to assess the usefulness of the in-depth review. Providing bases for athletic decision making on the use of weightlifting footwear amongst athletes, the identification of knowledge gaps, and future research development and enhancement. The studies were carried out by reading, grouping, and analyzing the publications.

## 3 Results and Discussion

Of the 13 articles included in the review, all of them were published in English. As for the place of publication, 05 (38.46%) were published in the United States of America, 04 (30.76%) in the United Kingdom, 02 (15.38%) in Canada, 01 (7.69%) in Sweden and 01 (7.69%) in Australia. Most articles published date from 2016 (5 or 38.46%) with a similar distribution of publications in the other years (Fig. 2).

Regarding the categories listed, with concern to the studies related to the comparison of a WLS with either the running shoe, flat soled shoe and barefoot conditions by analyzing their kinetic and or kinematic behavior. After analyzing the texts, the chosen articles were separated and the studies were identified and included in the present integrative review and their main results can be visualized (Table 1).

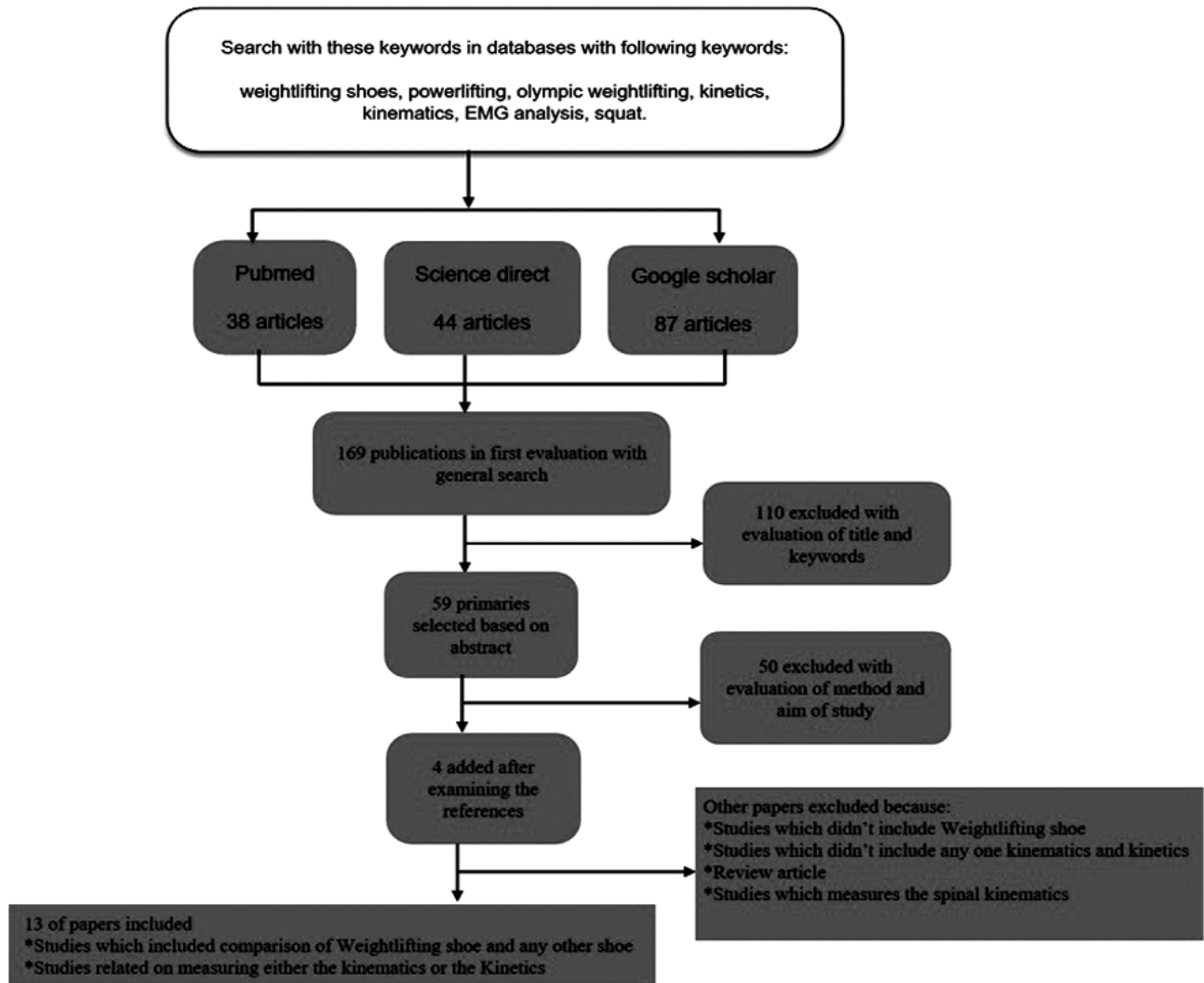


Fig. 1 —Flow chart of the literature search.

The content is collected and processed in four phases to extract information and summarize articles: recognition, selective, critical or reflective reading, and interpretative reading. The data is organized, analyzed, and interpreted so that the readers can understand it effectively. The authors developed a data evaluation instrument for this purpose, which included the following aspects and was tailored to the research objectives: identification of the origin of the articles, purpose of the study, summary of the results and authors conclusion from their understanding.

The findings are provided in a descriptive manner, allowing the reader to assess the usefulness of the comprehensive study, as well as to identify knowledge gaps such as development and improvement for future

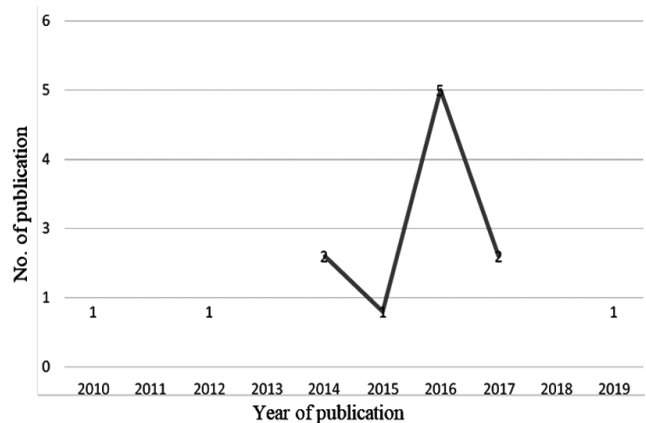


Fig. 2 —Time line of the publication included in the review.

Table 1 — Description of the tested conditions, control, tested load, and experience comparing weightlifting shoes with other type of footwear conditions.

Author	Studies on	Subjects	Subject-experience	Tested conditions	Control	Tested load	Exercise performed
Kimitake Sato <i>et al.</i> (2012) <sup>6</sup>	Kinematic study(2Dimensional motion analysis)	n=25	Experienced	Weightlifting shoe vs running shoes	Weightlifting shoes	60% of 1RM	Back squats
Dave Fortenbaugh <i>et al.</i> (2010) <sup>26</sup>	Kinematic study(2Dimensional motion analysis)	n=20	Experienced	Weightlifting shoe vs running shoes	Running shoes	60% of 1RM	Back squats
Hayley S Legg <i>et al.</i> (2016) <sup>27</sup>	Kinematic and Kinetic studies(3Dimensional motion analysis & ground reaction force)	n=32	Novice=16 Experienced=16	Weightlifting shoes vs athletic shoes	Athletic shoes	Unloaded=Free weights Loaded=75% of 1RM	Back squats
Anthony Josefsson. (2016) <sup>29</sup>	Kinematic study(2Dimensional motion analysis)	n=15	Experienced	Weightlifting shoe vs barefoot	Weightlifting shoes	50%,60% & 70% of 1RM	Back squats
Robert Needham <i>et al.</i> (2019) <sup>30</sup>	Kinematic study, Kinetic study(motion capture system and force plate ( and also center of pressure(COP)	n=1	Experienced	Weightlifting shoes vs Cross training shoes	Cross training shoes	80% of 1RM	Snatch and clean
Jonathan Sinclair <i>et al.</i> (2015) <sup>34</sup>	Kinematic and Kinetic studies(3Dimensional motion analysis & EMG analysis)	n=14	Experienced	Weightlifting shoe vs running shoes vs minimal shoe vs barefoot	Barefoot	70% of 1 RM	Back squats
Daniel J. Southwell <i>et al.</i> (2016) <sup>35</sup>	Kinematic and Kinetic studies	n=24	Experienced	weightlifting shoe vs barefoot vs running shoe	Weightlifting shoes	80% of 1RM	Back squats
Szu-Ping Lee <i>et al.</i> (2017) <sup>36</sup>	Kinematics and Kinetics	n=14	Recreational	Weightlifting shoes vs barefoot vs Heel raised platform	Barefoot	80% of 1RM	Back squats
Charlton JM, <i>et al.</i> ,(2017) <sup>37</sup>	The effects of a heel wedge on hip, pelvis, and trunk biomechanics during squatting.	n=14	Experienced (14)	Participants performed a barbell back squat under two conditions: With a heel wedge (WHW): Feet raised bilaterally with a 2.5-cm wooden block under the heels. Without a heel wedge (NHW): Barefoot squatting. The order of the conditions was randomized. Participants squatted to a self-selected depth to the lowest comfortable position possible while keeping their heels on the floor. A metronome set at 60 b/min <sup>21</sup> was used to standardize timing.	The study used a within-subject design, where each participant served as their own control by performing squats under both the heel wedge and barefoot conditions. The barefoot condition (NHW) acted as the comparison or control for the heel wedge condition.	Minimally loaded with a 20-kg Olympic barbell in a high-bar position	Barbell Backsquats
Sayers MG, <i>et al.</i> , (2020) <sup>38</sup>	Assessed the influence of various heel elevation conditions on spinal kinematic and kinetic data during loaded high-bar back squats	n=20	Novice (10) Experienced (10)	Participants performed squats in indoor shoes standing on either the flat level floor (LF) or with the heels elevated (EH) by standing on two wooden wedges machined to a 4.5-degree downslope . The regular weight training group also performed squats wearing specialist weightlifting shoes (WS) (adidas adiPower	The flat level floor (LF) condition served as a baseline for comparison with the heel-elevated conditions (EH and WS) within each group	Participants completed eight repetitions at two loading conditions: 25% of body weight (BW) and 50% of body weight (BW)	Back Squats

(Contd.)

Table 1 — Description of the Tested conditions, Control, Tested Load, and Experience comparing weightlifting shoes with other type of footwear conditions

Author	Studies on	Subjects	Subject-experience	Tested conditions	Control	Tested load	Exercise performed
				weightlifting shoes) which had a heel raised 20.1 mm relative to the forefoot, resulting in a mean decline angle of 4.4 degrees			
DonnellyDV, <i>et al.</i> ,(2006) <sup>39</sup>	The effect of the direction of gaze on the kinematics of the squat exercise.	n=10	Experienced (10)	Three different gaze directions while performing the squat: gazing downward, gazing straight ahead, and gazing upward.	The study used a repeated-measures design, where each subject performed the squat under all three gaze conditions, with the order counterbalanced.	The intensity for each subject was set at 25% of their maximum (1RM) in the squat exercise.	Squats
SinclairJ, <i>et al.</i> , (2020) <sup>40</sup>	The study aimed to explore the effects of different footwear on kinetics, kinematics, and muscle forces during the barbell back squat	n=24	Experienced (24)	Participants completed squats in four different footwear conditions: Adidas weightlifting shoe, Inov-8 weightlifting shoe, Cross-fit footwear, and minimal footwear . These were described with details on their average mass, heel thickness, and heel drop	Minimal footwear could be considered a reference point due to its minimal features (0 mm heel drop)	Participants completed squats at 70% of their 1 repetition maximum (1RM)	Back Squats
Gerwyn Hughes & Stephen Prescott <i>et al.</i> (2015) <sup>41</sup>	Kinematics and Kinetics(center of pressure excursion(CPE))	n=7	Recreational	Barefoot vs weightlifting shoe vs minimal shoe vs running shoe vs flat soled shoe	Barefoot	60% of 1RM	Back squats
George K. Beckham <i>et al.</i> (2014) <sup>42</sup>	Kinetics (EMG analysis)	n=12	Intermediate	Weightlifting shoes vs Running shoes	Running shoes	60%, 70% &80% of 1RM	Back squats
Alex Pilkinton <i>et al.</i> (2016) <sup>43</sup>	Kinetics(EMG analysis)	n=12	Experienced	Weightlifting shoes vs barefoot	Barefoot	80% of 1RM	Back squats
Joshua W. Cohen <i>et al.</i> (2017) <sup>44</sup>	Kinetics(COP value analysis)	n=17	Novice and advanced	Barefoot vs flat soled shoes vs weightlifting shoes	Barefoot & flat soled shoe	Unloaded=Free weights	Back squat
Wallace DA, <i>et al.</i> , (2002) <sup>45</sup>	Patellofemoral Joint Kinetics (Reaction Forces and Stress)	n=15	Healthy adults, free from orthopaedic injuries that would limit their ability to perform squatting techniques.	Patellofemoral joint kinetics (reaction forces and stress) while performing single-repetition squats to 90° of knee flexion, analyzed during eccentric (0–90°) and concentric (90–0°) phases, and at specific knee flexion angles (30°, 45°, 60°, 75°, and 90°).	Squatting performed without an external load (hands placed behind the head).	External load equivalent to 35% of the subject's body weight (using a 22-kg Olympic barbell with resistance plates positioned posteriorly across the shoulders).	Dynamic Squats
John W. Whitting <i>et al.</i> (2016) <sup>46</sup>	Kinematic and Kinetic studies(3Dimensional motion analysis & ground reaction force)	n=9	Experienced	Running shoe vs Weightlifting shoe	Running shoes	50%,70% & 90% of 1RM	Back squats
Lorenzetti S, <i>et al.</i> , (2018) <sup>47</sup>	Effects of stance width, foot placement angle, experience, and load on squat biomechanics (knee, hip, trunk motion, and loading)	n=42	Novice (21), Experienced (21)	3 stance widths (narrow, hip, wide), 3 foot placement angles (0°, 21°, 42°), combining for 9 different positions. Experienced group also tested with additional load.	Not explicitly stated as a separate control group, but comparisons are made between novice and experienced groups.	0% body weight (novice and experienced), 50% body weight (experienced only)	Back squats (Contd.)

Table 1 — Description of the Tested conditions, Control, Tested Load, and Experience comparing weightlifting shoes with other type of footwear conditions

Author	Studies on	Subjects	Subject-experience	Tested conditions	Control	Tested load	Exercise performed
Myer GD, <i>et al.</i> ,(2014) <sup>48</sup>	Proposed assessment of functional deficits and technical factors limiting back squat performance; development of a dynamic screening tool.	n=0	NA	The proposed Back Squat Assessment (BSA) involves observing 10 continuous bodyweight back squat repetitions from anterior, posterior, and lateral perspectives, evaluating 10 criteria across upper body, lower body, and movement mechanics domains.	and between unloaded and loaded conditions within the experienced group NA	Body Weight	Backsquats
FryAC, <i>et al.</i> ,(2003) <sup>51</sup>	Effect of knee position on hip and knee torques during the barbell squat	n=7	Experienced (7)	Two variations of parallel barbell squats: unrestricted (knees permitted to move anteriorly past the toes) and restricted (a wooden barrier prevented knees from moving anteriorly past the toes)	The study design used repeated measures comparing the two conditions within the same subjects, rather than a separate control group	Body Weight	Barbell Squats
ButlerRJ, <i>et al.</i> ,(2010) <sup>52</sup>	Biomechanical analysis of the different classifications of the Functional Movement Screen (FMS) deep squat test.	n=28	Experienced (28)	Participants performed the deep squat per FMS guidelines at a self-selected pace. Motion analysis data were collected on the right side only. Participants wore standardized laboratory running shoes and laboratory spandex shorts and shirt.	Participants were categorized into three groups (1, 2, and 3) based on their FMS deep squat score, and comparisons were made between these groups.	Body Weight	Deep Squats

research. The analyses are performed through the reading, grouping and analysis of the articles

Three primary themes emerged after summarizing the surveys contained in this review: relevance of WLS and any other shoe or barefoot to the kinematics; relevance of WLS and any other shoe or barefoot to the kinetics and relevance of WLS and any other shoe or barefoot to the combined application of kinematics and kinetics. A total of thirteen articles have been selected for final evaluation. Of the 13 articles included, 3(23.07%) referred to the relevance to the kinematics, 3(23.07%) to the kinetics and 7(53.84%) to the combined relevance to the kinematics and kinetics. A detailed summary of Results and Conclusions presented on the WLS comparing with other types of footwear conditions within the mentioned themes of this study (Table 2).

**3.1 Kinematics**

Among the studies included in this review, it was identified that the WLS reduces the overall anterior bar displacement combined with the posterior hip displacement thereby reducing the forward bending of the trunk and reducing the stress in the lower back of the person who trains wearing the WLS and thus helps to maintain a more upright torso<sup>2</sup>. This study further states that the athlete training while wearing a WLS gets a maximum ankle peak flexion which will help them to maintain a more vertical shank.

Another two dimensional kinematic study done by Sato *et al.*<sup>28</sup> indicates that the WLS provides a less trunk lean with a greater foot segment angle than a running shoe. But it doesn't provide any difference in the peak flexion angle to the thigh segment. The study further suggests that the WLS should be worn by any athlete who is well experienced and wants to train

Table 2 — Summary of Results and Conclusions presented on the WLS comparing with other type of footwear conditions

Author	Origin	Purpose	Type of source	Results ® and Conclusion ©
Kimitate Sato <i>et al.</i> (2012) <sup>6</sup>	USA	To validate a higher degree of foot segment angle on wearing WLS and compare the kinematic differences between WLS and running shoes during barbell back squats	Research	R= Significant difference observed in trunk lean displacement (F [1,24] =5.57, p<0.05) with an effect size of 0.42, foot segment angle (F [1,24] =15.87, p<0.05) with an effect size of 0.72, no difference in peak thigh segment flexion angle (F [1,24] =0.84, p=0.37). C= WLS alters the squat technique by minimizing the forward trunk lean displacement and increasing the foot segment angle(placing the ankle in a plantar-flexed position).
Dave Fortenbaugh <i>et al.</i> (2010) <sup>26</sup>	USA	To compare the kinematics between running shoe and WLS while performing Barbell back squats	Research	R= Significantly less horizontal trunk displacement and more vertical shank position while performing in WLS C= WLS allows for more vertical shank position and erect posture during squatting
Hayley S Legg <i>et al.</i> (2016) <sup>27</sup>	UK	To study the Kinetics and Kinematics of using a WLS	Research	R=The WLS elicited a reduction in ankle dorsiflexion and an increase in knee flexion on all the trails. The decline angle of WLS reduces the demand of the ankle joint C=Athletes who have limited squat depth can be benefitted by performing in WLS
Anthony Josefsson. (2016) <sup>29</sup>	Sweden	To compare the kinematic differences in sagittal plane performing back squat wearing WLS and barefoot	Research Thesis	R= no statistical significance in hip angle at 50% of 1RM(p=0,370) or at 70%(p=0,053) but a statistical difference in hip angle at 60%(p=0,028), no statistical difference in ankle angle at 50% of 1RM(p=0,997),60%(p=0,0182) or 70%0,332). C=No significant difference will come from wearing either of the shoes taken in this study
Robert Needham <i>et al.</i> (2019) <sup>30</sup>	UK	To validate the necessity of a WLS for the sport of weightlifting	Research	R=Greater extension of thorax segment was observed for the snatch in comparison to the clean, a greater load is on the forefoot while using another type of shoe taken for experiment when compared to the WLS for the snatch. C=The WLS provided a greater thigh flexion, they provide a higher contact area which indicates a greater stability
Jonathan Sinclair <i>et al.</i> (2015) <sup>34</sup>	UK	To compare the effects of various footwear on the 3-D kinematics and muscle activation potentials during barbell back squats	Research	R=The chi-square test was significant ( $\chi^2 = 4.14, p < 0.05$ ) indicated the majority preferring barefoot A significant main effect ( $g2 p = 0.36$ ) was also observed for the magnitude of squat depth. C=Footwear can significantly influence the kinematics and the EMG potentials of the barbell back squats
Daniel J. Southwell <i>et al.</i> (2016) <sup>35</sup>	Canada	To quantify a 3-Dimensional lower limb net joint moments and lumbosacral compression and shear forces when performing barbell back squats wearing different shoe conditions	Research	R=In peak net joint moment Post-hoc testing revealed knee extension moment exhibited greater magnitude in the running shoe (0.123Nm/kg) and WLS (0.284Nm/kg) conditions than in barefoot condition, In peak joint and segment angles knee internal rotation were significantly greater in the WLS compared to barefoot (+2.0°) and running shoe (+1.1°), In peak spinal compression and shear forces there were no significant main effects, In vertical centre of mass trajectory post-hoc testing revealed that WLS and running shoe produced deeper squats (~1cm) than did the barefoot condition (p=0.002 and p<0.001) C=Footwear conditions when altered provides only marginal redistribution of the biomechanical loading amongst the lower extremity joints during the back squat exercise.
Szu-Ping Lee <i>et al.</i> (2017) <sup>36</sup>	USA	To compare the trunk and lower extremity biomechanics during barbell back squats in 3 foot postures	Research	R=none of the heel raised foot postures affected the trunk and lower extremity muscle activation [thoracolumbar paraspinal (p=0.179), knee extensor (p=0.507)] or the trunk angles [thoracolumbar spine (p=0.348), lumbar spine (p=0.283)] during the squat. C=Olympic weightlifters can find advantages on using WLS since they are required to perform deeper squats, for recreational weightlifters the choice of footwear is not that important
Charlton JM, <i>et al.</i> ,(2017) <sup>37</sup>	Canada	To examine the effects of heel wedges compared with barefoot on minimally loaded barbell back squats in resistance trained individuals,	Research	R = The heel wedge condition elicited significantly less forward trunk flexion angles and less anterior pelvic tilt at peak knee flexion compared with barefoot conditions. Peak hip flexion angle significantly decreased when squatting with wedges compared with no wedges. Peak knee flexion angles

(Contd.)

Table 2 — Summary of Results and Conclusions presented on the WLS comparing with other type of footwear conditions

Author	Origin	Purpose	Type of source	Results ® and Conclusion ©
		specifically investigating pelvis and trunk kinematics, hip joint kinetics, and hip and thigh muscle activation		significantly increased when squatting with wedges compared with no wedges. No significant differences were found between conditions for peak ankle dorsiflexion angles. C = Heel wedges may be a viable modification for reduction of excessive forward trunk flexion and hip joint moments during barbell back squats . However, they do not appear to affect the maintenance of a neutral spine (based on the relative trunk-pelvis angle) . Therefore, while beneficial for reducing excessive forward trunk flexion and hip load, heel wedges may not be sufficient to address issues related to lumbar flexion
Sayers MG, <i>et al.</i> , (2020) <sup>38</sup>	Australia & Switzerland	To assess the influence of various heel elevation conditions on spinal kinematic and kinetic data during loaded high-bar back squats in trained and novice weight trainers	Research	R = Novice weight trainers had greater moments around L4/L5 than regular weight trainers during the last 20% of the lift in the level floor condition, but this difference became non-significant with elevated heels. Lifting the heels during back squats (with elevated heels or weightlifting shoes) had limited significant influences on spinal kinematics and kinetics, particularly in regular weight trainers. The spinal kinematics and kinetics of novice weight trainers became similar to those of the regular weight training group during the elevated heels condition C = From a spinal safety perspective, it appears advantageous for novice weight trainers to perform back squats with slightly elevated heels. Regular weight trainers appear to realize only limited benefits from elevating their heels
Donnelly DV, <i>et al.</i> ,(2006) <sup>39</sup>	Newyork	The study aimed to determine if the direction of gaze influences the kinematics of the squat exercise.	Research	R = The study found overall similarity in movement kinematics across the three gaze directions (downward, straight, and upward). However, the downward gaze increased the extent of hip flexion (especially compared to the upward gaze) and possibly trunk flexion. No significant differences were found in postural sway or stability based on gaze direction. C = Cautioning athletes against allowing their head or gaze to drop below a neutral position during squats appears warranted, as excessive hip and trunk flexion are considered contraindicated and may increase injury risk.
SinclairJ, <i>et al.</i> , (2020) <sup>40</sup>	UK	To explore the effects of different footwear on kinetics, kinematics and muscle forces during the barbell back squat in male and female lifters using Bayesian modelling.	Research	R = Peak quadriceps force and concentric impulse were greater in Adidas, Cross-fit, and Inov-8 conditions compared to minimal footwear. Peak patellofemoral stress and patellar tendon forces were also greater in Adidas, Cross-fit, and Inov-8 conditions compared to minimal footwear. Trunk angular ROM was greater in minimal footwear compared to Adidas and Inov-8. Minimal footwear increased total and eccentric squat time and reduced peak vertical GRF and peak power (in males), but reduced patellofemoral/patellar tendon loading. Male lifters preferred Adidas, females had no significant preference. C = Weightlifting and Cross-fit footwear may enhance lower extremity muscle development and improve squat biomechanics by reducing trunk angulation, but this is likely at the expense of increased knee joint loading. Minimal footwear may reduce knee joint loading but affects other kinetic and temporal parameters.
Gerwyn Hughes & Stephen Prescott <i>et al.</i> (2015) <sup>41</sup>	UK	To investigate the effects of footwear on COPE and sagittal plane kinematics during the back squat	Research	R=No significant difference in COPE between any of the footwear conditions (p>0.05) C=The WLS should be worn while performing back squats to ensure lower limb joints are able to move through their full range of motion whilst maintaining stability
George K. Beckham <i>et al.</i> (2014) <sup>42</sup>	USA	To compare the EMG activity during Back squat with WLS and Running shoes	Research	R=Running shoes shown to exhibit more muscle activity compared to the WLS, EMG activity increases with load. C=The choice of footwear does affect the muscle activity during the back squat, the load and shoe choice will interact with the muscle activation.

(Contd.)

Table 2 — Summary of Results and Conclusions presented on the WLS comparing with other type of footwear conditions

Author	Origin	Purpose	Type of source	Results ® and Conclusion ©
Alex Pilkinton <i>et al.</i> (2016) <sup>43</sup>	USA	To investigate the Barbell Back squat comparing WLS and barefoot	Research Thesis	R= There were statistical differences between phases but no statistical difference between the footwear conditions C=Both the phases indicate differences in kinematics and can provide the effectiveness of one modality over another, The muscle activation pattern of both WLS and barefoot conditions remain consistent and this supports the usage of both the methods for improving the muscle activation patterns of the tibialis anterior muscles and peroneal muscles.
Joshua W. Cohen <i>et al.</i> (2017) <sup>44</sup>	Canada	To compare the effects of different footwear on balance during barbell back squat amongst novice and advanced participants	Research	R=The main difference between WLS and other conditions are the addition of 1.5" heel lift, Kinematic changes at the ankles will influence adjustments at the hip, WLS leads to safer squats as less shear forces are applied to the lower back C=The WLS condition regulated balance better than a barefoot and flat soled shoe conditions, thereby the WLS provides an increased balance performance by mitigating the risk of falling and injury during squat movements.
Wallace DA, <i>et al.</i> , (2002) <sup>45</sup>	California	To measure and analyze patellofemoral joint reaction forces (forces acting on the patellofemoral joint) and stress (pressure experienced by the joint) during squats.	Research	<ul style="list-style-type: none"> <li>• R = In both unloaded (no weights) and loaded (with weights) squat conditions: Knee extensor moments, patellofemoral joint reaction forces, and stress increased as knee flexion angles became greater. These values peaked at a knee flexion angle of 90°. In loaded trials (with weights), patellofemoral joint stress was significantly higher at deeper flexion angles:</li> <li>• 45° to 90° eccentric phase: The lowering phase of the squat.</li> <li>• 75° to 90° concentric phase: The rising phase of the squat.</li> <li>• C = Patellofemoral joint stress increases linearly with greater knee flexion angles. Adding an external load further increases joint stress. To reduce stress on the patellofemoral joint during squats: Avoid excessive knee flexion angles (e.g., terminal flexion at 90° or deeper).</li> </ul>
John W. Whitting <i>et al.</i> (2016) <sup>46</sup>	Australia	To Compare the influence of different footwear on squats using different loads	Research	R=The was no significant changes in selected kinematic measures except for peak ankle dorsiflexion angles. C= Overall safety and technique of the lift is substantially affected by the choice of footwear the athlete wears , further studies are required to bring evidence to this.
Lorenzetti S, <i>et al.</i> , (2018) <sup>47</sup>	Switzerland	To evaluate the effect of narrow, hip, and wide stance widths, foot position angles (0°, 21°, and 42°), strength exercise experience, and barbell load (0 and 50% body weight) on knee, hip, and trunk motion and loading during squatting.	Research	R=Both stance width and foot placement angle influenced hip and knee joint moments and range of motion; mediolateral knee displacement was affected by stance, foot angle, experience, and load. Extreme positions (WS-0° and NS-42°) resulted in increased mediolateral knee displacement and specific knee alignment tendencies. C= Choose squat stance and foot placement based on targeted joint moments, avoiding extremes (NS-42° and WS-0°) due to high joint moments; moderate stance and foot angles are generally recommended for minimizing mediolateral knee displacement, and added weight did not significantly impact lower back moments.
Myer GD, <i>et al.</i> , (2014) <sup>48</sup>	USA	The primary purpose is to deconstruct the technical aspects of the back-squat exercise and introduce a novel dynamic screening tool designed to identify functional deficits that may limit performance and increase the risk of injury	Research	R = The back squat is presented as a valuable tool to identify biomechanical deficits related to neuromuscular control, strength/stability, and mobility within the kinetic chain. Observed movement impairments during the back squat, guided by the proposed assessment tool, may indicate elevated injury risk and suboptimal physical performance. Common deficits identified during the back squat include issues with head, thoracic, and trunk position, hip position asymmetry, frontal plane knee alignment (valgus/varus), tibial translation angle, and foot position (e.g., lifting heels).

(Contd.)

Table 2 — Summary of Results and Conclusions presented on the WLS comparing with other type of footwear conditions

Author	Origin	Purpose	Type of source	Results ® and Conclusion ©
Reiman MP, <i>et al.</i> , (2011) <sup>49</sup>	USA	To outline the current evidence supporting the utilisation of training principles in athletic rehabilitation and provide suggested implementation of these principles throughout different phases of a proposed rehabilitation program	Research	<p>C = The unloaded back squat assessment serves as a guide for practitioners to identify biomechanical deficits in athletes, particularly youth, before engaging in more advanced training.</p> <p>R = Currently, evidence is lacking regarding the comprehensive integration of strength and conditioning principles into rehabilitation programs for injured athletes. Numerous methods are suggested for clinicians to potentially utilize to improve strength, power, speed, endurance, and metabolic capacity.</p> <p>C = Despite abundant information on implementing training principles in strength and conditioning for healthy individuals, research on using these principles in properly designed rehabilitation programs for injured athletes is insufficient. Future studies are needed to investigate the role of these principles in athletic rehabilitation.</p>
FryAC, <i>et al.</i> ,(2003) <sup>51</sup>	USA	To compare torques at the knee and hip joints during parallel barbell squats when anterior knee movement is restricted versus unrestricted	Research	<p>R = Restricted squats significantly increased hip torque and decreased knee torque compared to unrestricted squats.</p> <p>C = Permitting slight forward knee displacement during barbell squats may be necessary for proper torso positioning and optimizing forces across all involved joints, potentially reducing inappropriate stress on the hips and low back region.</p>
ButlerRJ, <i>et al.</i> ,(2010) <sup>52</sup>	USA	To examine the peak sagittal plane joint angles and joint moments of the lower extremity during the deep squat (DS) movement of the Functional Movement Screen (FMS) to assess differences between the classifications	Research	<p>R = Lower extremity mechanics differed between the various levels of the FMS deep squat. Group 3 exhibited greater dorsiflexion excursion compared to Group 1. There was a large effect size difference between Group 1 and Group 3 for peak dorsiflexion, and a moderate effect size difference between Group 2 and Group 3. Group 3 had greater peak knee flexion and greater joint excursion than Group 2, which in turn had greater values than Group 1. Group 3 also showed greater peak knee extension moments compared to Group 1. Groups 2 and 3 exhibited greater peak hip flexion, hip flexion excursion, and peak hip extension moments compared to Group 1.</p> <p>C = It appears that individuals who score differently on the deep squat as determined by the FMS exhibit differences in mechanics that may be beneficial when assessing strategies for interventions. Future research should assess how fundamental changes in mobility and stability independently can affect performance on the deep squat.</p>

for a longer duration without any worry about the occurrence of any kind of low back pain and also suggests why the experienced athletes should always wear a WLS rather than a running shoe which eventually aids in them to maintain a more upright torso.

Research indicates that the raised heel in a WLS is for the reason of when the ankle range is restricted which happens predominantly due to the athletes having an ankle mobility issue the knee will be unable to flex maximally without assistance like a declined surface<sup>4</sup>. According to Kongsgaard M *et al.*<sup>7</sup> another benefit of having a heel raise which is found in the WLS and not in the running shoes actually aids in the strengthening of the knee extensor muscles.

According to Josefsson A *et al.*<sup>29</sup>, an experienced set of athletes with 50%, 60% & 70% of the 1

Repetition Maximum (RM) indicated that the WLS provided no statistical differences in the hip angle at both 50% and 70 % but it did provide some significant statistical difference in the 60% of 1RM load, also there is no statistical difference in the ankle angle in all the 3 different loads. Due to the lack of evidence to claim that the WLS is beneficial for the wearer, it is hence not recommended for training.

WLS benefit an experienced weightlifter more than an inexperienced novice weightlifter. when worn by the athletes, it decreases the ankle range of motion and increases the hip and knee flexion thus providing the athletes with a more upright stable posture than when they perform squats in a regular athletic shoe. In addition to this, the experienced group of athletes witnessed an increase in knee and hip flexion when compared to the novice lifter, also that the female

athletes had a higher hip flexion when compared to men in unloaded barbell squat condition<sup>32</sup>.

This difference is also evident in the study done by Zeller BL *et al.*<sup>33</sup> on the single leg squat. This is due to the fact that the difference in the hip anatomy and flexibility range between both sexes account for this. In a study to determine the effects of WLS on an athlete when they perform the snatch and clean, Needham R *et al.*<sup>31</sup> address that greater thigh flexion is noticed for WLS and also greater thorax extension for the snatch is obtained.

According to Sinclair J *et al.*<sup>34</sup>, WLS didn't provide much of a benefit to the muscle activation pattern and also it didn't increase the squat depth whereas the running shoe exhibited a deeper squat and also high muscular activation pattern. The barefoot training increased the foot proprioception and thus the majority of the subjects preferred the barefoot conditions rather than the running shoe or the WLS conditions. The knee extension moments were great in running shoes and WLS, knee external rotation is high in WLS, hip moments are larger in barefoot training, hip external and hip internal moments are larger during barefoot training, and no effect of footwear on low back conditions, ankle dorsiflexion is higher in barefoot training condition, the global trunk lean is higher in the barefoot condition than the WLS and running shoe, Deeper squats are produced in WLS and running shoe.

Southwell DJ *et al.*<sup>35</sup> suggests that the three footwear condition analyzed provided only marginal difference between them and it can be used to benefit the athlete when a WLS has been used in the training regularly over a long period of time by aiding in the development of the musculoskeletal system of the body.

There is no significant difference in the thoracic, lumbar and knee kinematics, a slight increase in knee flexion happens when wearing WLS and squatting on a raised platform, which results in squatting much deeper. so Lee SP *et al.*<sup>36</sup> suggest that the WLS doesn't provide much of a benefit to the recreational weightlifter whereas it does help the experienced weightlifters to squat even deeper by restricting the ankle dorsiflexion.

According to Charlton, *et al.*<sup>37</sup> examining the biomechanical impact of heel wedges on barbell back squats. Analyzing 3D kinematics, hip kinetics, and select muscle EMG activity. The heel wedge condition significantly reduced forward trunk flexion and anterior pelvic tilt at peak knee flexion and decreased external

sagittal hip joint moments compared to the barefoot condition. While peak hip flexion decreased and peak knee flexion increased with the wedge, the relative angle between the trunk and pelvis remained unchanged. So heel wedges can effectively reduce forward trunk flexion and hip joint loads, supporting their use for managing trunk lean and potentially aiding hip rehabilitation, but cautioned that they do not improve trunk-pelvis neutrality, suggesting they are not a singular solution for lumbar flexion issues.

Recent biomechanical investigations, including studies focusing on the impact of heel elevation, squat depth, and stance mechanics, shed light on these complexities. Research indicates that elevating the heels during back squats, whether through inclined boards or weightlifting shoes, appears to have minimal significant influence on spinal kinematics and kinetics in experienced weight trainers. However, for novice weight trainers, heel elevation may offer potential spinal safety benefits by reducing external joint moments about the lower lumbar spine during critical phases of the lift. Furthermore, studies comparing restricted and unrestricted squatting techniques suggest that allowing greater knee flexion may result in reduced lumbar flexion and lower stress on the back. The choice of stance width and foot placement angle also significantly impacts lower limb and trunk loading, emphasizing the need for individualized technique considerations<sup>38</sup>. Overall squat kinematics were largely similar across downward, straight, and upward gaze conditions, gazing downward increased hip flexion and potentially trunk flexion compared to gazing upward. However, the study found no significant impact of gaze direction on postural sway or stability during the squat. The athletes should be cautioned against looking below a neutral position during squats might be beneficial to avoid excessive hip and trunk flexion, which are associated with increased risk of lower back injury<sup>39</sup>.

### 3.2 Kinetics

According to Legg HS *et al.*<sup>27</sup>, WLS modifies the kinetic characteristics of the athlete and makes them more stable and able to maintain an upright torso while back squatting. In a study by Needham R *et al.*<sup>30</sup>, WLS increase the ground contact area and also help in increasing the stability of the body by increasing its COP in the in-foot surface area.

The running shoes provide higher muscle activation, barefoot training increases foot proprioception and there

by most of the athletes preferred to squat barefoot. So Sinclair J *et al.*<sup>40</sup> suggests that the running shoe increases the muscle activity when used for squatting and to increase foot proprioception, the athlete needs to perform squat in barefoot regularly which aids in the increase in the foot to ground contact sensation.

Research indicates that the WLS increases kinetic values compared to barefoot & running shoes which exhibited a similar result and only a marginal difference in the kinetic values, but Southwell DJ *et al.*<sup>35</sup> address that this result cannot be justified that the WLS will be benefitting the athletes in just the first time they are performing but it will increase the musculoskeletal formation when the athletes carry out training wearing them for a long time.

In another similar research, Lee SP *et al.*<sup>36</sup> say that the WLS doesn't provide much of a difference when it comes to increasing the kinetic values in the tests. The result of this particular study does not recommend the use of WLS to prevent low back pain occurrence and for increasing stability, although this study involved quite a higher number of subjects for the analysis but it should also be observed that these tests have been carried out on recreational weightlifters and not on regular experienced weightlifters, as it has been studied from earlier research papers that the experienced weightlifters will develop a more mechanized kinetic link and thus making their every squat very similar and making them look in exactly the same pattern which won't happen in a recreational athlete as they are inexperienced and their lack of proper form and technique will lead to their poor performance and we cannot conclude that their poor performance in the lift is due to the footwear they have worn<sup>41,42</sup>.

According to Pilkinton AW *et al.*<sup>43</sup>, the WLS and barefoot exhibit the same amount of muscle activation in EMG analysis and the WLS provide more ankle stability and also it provides better safety on the weightlifting floor than the barefoot training condition. WLS also provides a better balance than the other two conditions such as barefoot and running shoe. Joshua W. Cohen PL *et al.*<sup>44</sup> suggest that by using WLS the athlete's balance and performance will increase thereby reducing the chance and possibility of falling while performing the lift and also reducing the occurrence of any injuries.

According to Wallace *et al.*<sup>45</sup> patellofemoral joint kinetics during loaded (35% BW) and unloaded squats in healthy adults are reaction forces and stress increased significantly with greater knee flexion

and were further elevated with external loading, particularly at deeper angles.

#### 4 Conclusion

This systematic review identifies thirteen studies from the literature search that the authors found comparing WLS with other forms of footwear conditions on the basis of Kinematics and Kinetic behavioral changes.

The WLS alters the Kinematics and Kinetics of experienced athletes greatly and this should be considered from the studies while they don't provide much of a performance enhancement for inexperienced athletes. The findings of this review tell us that the WLS improves and keeps the athletes in a more upright posture with more balance and help them to attain a deeper squat. The WLS can be used in aiding muscle activation, getting better balance with stability and preventing any injury risks.

The results of a few of the reviewed studies don't suggest the use of WLS on athletes. But these studies don't provide significant evidence which justifies the WLS is worse than any other footwear conditions such as running shoes, minimalistic shoes, athletic shoes, barefoot and cross training shoes for squatting. There is a need for a more detailed study to ensure that the WLS alters the Kinematic and kinetics of all kinds of athletes. Studies using a higher number of subjects and more diverse categories of men and women of different weight categories and also a different level of experience category especially novice and intermediate level of an athlete needed to support the positive effects of WLS on all kinds of athletes.

We hope that with this review, all experienced athletes who perform squats and any kind of lifting movement that involves squatting should be provided with a WLS to meet their needs, as this should improve their performance and reduce the chances of injuries.

#### Acknowledgment

The author thanks CSIR-CLRI for permitting access to their facilities in the shoe & Product Design Centre (SPDC) and also one of the author thanks CSIR- Senior Research fellowship for the funding provided. CSIR-CLRI communication code: 1746

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