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The Effect of Ankle Dorsiflexion on Sagittal Posture and Core Muscle Activation

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Abstract: Maintaining proper posture is essential for preventing musculoskeletal disorders and reducing injury risks. This study investigates the impact of insoles with ankle dorsiflexion (inverted drop sole) on sagittal posture, spinal curvatures, and core muscle activation. Methods: Fifty-five participants (29 men, 26 women; aged 20–70 years) were evaluated in two conditions: barefoot and with insoles incorporating an inverted drop sole. Kinematic data of trunk, hip, and knee angles, along with spinal curvatures (dorsal kyphosis, lumbar lordosis, and sacral slope), were collected using the Simi Aktysis 3D system and the Medi Mouse IDIAG 360®. The electromyographic (EMG) activity of the rectus abdominis and rectus femoris muscles was analyzed using the Bioplux® device. Statistical analyses were conducted using Wilcoxon tests (W) for non-parametric data and Student's *t*-tests (T) for parametric data with significance set at $p < 0.05$. For parametric data, effect size (ES) was used to assess the magnitude of differences based on the Cohen scale. For nonparametric data, the rank biserial correlation (rB) was used, considered an ES equivalent to the correlation coefficient. Results: Significant differences were observed between the barefoot and insole conditions for trunk and knee angles ($p = 0.009$ and $p < 0.001$, respectively) with moderate and large magnitude of difference (rB = −0.41 and rB = −0.96, respectively). No significant change in hip angle ($p = 0.162$) was observed. Spinal curvatures, including dorsal kyphosis, lumbar lordosis, and sacral slope, significantly decreased ($p < 0.001$), with a large magnitude of difference for dorsal kyphosis, lumbar lordosis, and sacral scope (rB = 0.71, rB = −0.94 and ES = 0.54, respectively). EMG analysis revealed the increased activation of the *rectus abdominis* and *rectus femoris* muscles ($p < 0.001$), with a large magnitude of difference both the *rectus abdominis* and *rectus femoris* (rB = −0.82, and ES = −0.82, respectively). Conclusions: Insoles with ankle dorsiflexion significantly improve sagittal posture by reducing spinal curvatures and enhancing core muscle activation. These findings suggest that dorsiflexion technology in footwear may serve as a non-invasive strategy for improving posture, preventing musculoskeletal disorders, and managing low back pain.

Keywords: kinematics; gait; electromyography; spinal alignment; inverted drop sole; low back pain

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Citation: Reis e Silva, M.; Lerebourg, L. The Effect of Ankle Dorsiflexion on Sagittal Posture and Core Muscle Activation. *Biomechanics* **2024**, *4*, 812–826. https://doi.org/10.3390/biomechanics4040060

Academic Editor: Urs Granacher

Received: 18 September 2024
Revised: 27 November 2024
Accepted: 5 December 2024
Published: 23 December 2024

1. Introduction

In 2020, 619 million people worldwide suffered from low back pain (LBP), and projections indicate that this number will increase to 843 million by 2050, largely driven by population growth and aging [1]. LBP is one of the most prevalent musculoskeletal disorders globally, affecting individuals across all age groups and significantly contributing to disability and reduced quality of life [2,3]. LBP is often associated with substantial socioeconomic burdens, making it a primary focus of public health interventions [1,4,5]. Research indicates that the etiology of LBP is multifactorial, with significant contributions from age, sex, genetic predisposition, poor ergonomics, functional impairments, sedentary lifestyles with increasing obesity rates, and environmental influences, alongside occupational factors [6–10]. For example, the study conducted by Glowinski et al. indicates that approximately 91.7% of physiotherapists have experienced episodes of spinal pain during their careers, with the majority of these pains localized in the lumbar region (82%) and the cervical region (67%) [7]. The most common causes of pain were identified as lifting heavy loads (62.6%) and trunk flexion (37.4%). Effective prevention and management strategies can then be adopted [7–9]. Indeed, current interventions for LBP range from conservative treatments such as physical therapy, exercise, and ergonomic adjustments to more invasive procedures like injections and surgery [7,11]. While physical activity appears to reduce the frequency of pain episodes in occupational activities [7], it is also interesting to analyze the role of shoes and orthopedic insoles as a non-invasive approach that can influence gait mechanics, redistribute the load, and potentially improve posture [12,13].

At present, there is a wide variety of shoes or insoles available, such as open-toed sandals, flat shoes, heeled shoes, safety shoes, athletic shoes, and negative-heel shoes, each utilizing different technologies to alleviate discomfort or pain [14–16], improve recovery [17], or prevent injuries [18]. Numerous reviews have indicated that footwear or shoe devices can have a significant impact on gait and posture [19–22], muscle activity [20,23,24], and peripheral venous return [25,26], both immediately and over a prolonged period [21–23]. Among these non-invasive shoe devices, there has been an increasing interest in recent years regarding the impact of negative-heel shoes (i.e., footwear or shoe devices that reduce the height of the heel in relation to the front part of the foot), resulting in an augmented dorsiflexion [27–29], and altering the biomechanics of walking and standing [27,28]. This design shifts the center of pressure towards the forefoot, engaging lower limb muscles differently than standard footwear. Studies examining dorsiflexion shoes have reported that dorsiflexion priming activates lower limb musculature differently during locomotion compared with standard shoes [27,28]. Bourgit et al. demonstrated a notable rise in the electromyographic (EMG) activity of the triceps surae and tibialis anterior muscles [27]. Li and Hong showed that negative-heeled gait resulted in a significantly larger integrated EMG value, a longer duration of EMG activity, and a higher mean amplitude of EMG activity in the tibialis anterior, lateral gastrocnemius, and biceps femoris muscles [28]. They proposed that alterations in muscle recruitment patterns, which are associated with the balancing function of these muscles, may have contributed to this outcome. Another possible explanation for these findings could be the foot position, which mechanically creates a longer lever, leading to heightened neuromuscular activity in the targeted muscle due to the increased applied forces. Furthermore, research on dorsiflexion shoes has indicated enhancements in vertical jump height, along with advancements in sprint speed or jumping performance when compared to the use of conventional shoes [30,31].

Although some studies have examined the effects of inverted drop sole (i.e., insoles) [13], evidence remains limited, and the precise mechanisms by which these shoes impact spinal posture and alleviate pain are not yet fully understood. Given the biomechanical stresses associated with posture and repetitive movements, for example, in professional settings, analyzing sagittal balance parameters is essential in both managing and preventing LBP [4,9,15,32]. Previous research has emphasized the link between pelvic tilt and lumbar lordosis [33,34], showing that pelvic anteversion increases the sacral slope, which, in turn, heightens lumbar lordosis [35,36]. This increased curvature exerts greater compressive forces on the posterior vertebral structures, potentially exacerbating LBP [37,38]. Therefore, this study aims to investigate the effects of inverted drop soles (insoles) on sagittal posture, such as the kinematic parameters of the lower limbs (i.e., trunk, hip, and knee angles) and lower back (i.e., spinal curvature angles), as well as EMG activities (i.e., rectus abdominis and rectus femoris). The hypothesis is that these insoles may help reduce spinal curvatures and enhance core muscle engagement, ultimately contributing to LBP prevention and management.

2. Materials and Methods

This study included adults aged 18 years and older. Participants were excluded if they reported musculoskeletal pain in the past week, were pregnant, had a history of neurological conditions affecting sensory or motor functions, or were visually impaired. LBP was measured using a structured questionnaire consisting of multiple-choice questions (e.g., demographic items, type of sporting activity and frequency of training sessions, lifestyle, presence of LBP), self-administered, to investigate the prevalence of LBP [39,40]. Participants were categorized based on their LBP history as having never experienced LBP, having less than 3 months of LBP, or having more than 3 months of LBP during their lifetime [39,40]. The socio-demographics, anthropometric characteristics, and pain ratings of the subjects are presented in the Section 3 (Table 1). All participants provided informed consent after being briefed about the study's risks and benefits. The study protocol was approved by the institutional ethics committee. The participants were blinded to the specific characteristics of the insoles used in the study.

Table 1. Socio-demographics, anthropometric characteristics, and pain ratings of the subjects.

	Subjects (n = 55)
Age (years)	43.1 ± 12.1
Height	170.9 ± 8.2
Weight (kg)	68.7 ± 10.4
Body mass index (kg·m^{-2})	23.5 ± 2.9
Back pain (n)	
Never	13
<3 month back pain	29
>3 month back pain	13

2.1. Insole Geometry

The intervention utilized insoles specifically designed to promote ankle dorsiflexion. The insoles were composed of three distinct sections (Figure 1): (1) a forefoot section elevated to 10 mm, (2) an intermediate transition zone, and (3) a rearfoot section with no elevation. The participants' feet were positioned so that the metatarsophalangeal joints rested on the forefoot section, ensuring consistent placement relative to each participant's foot size.

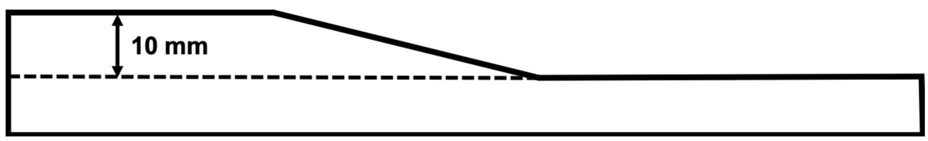

Figure 1. Illustration of insole geometry.

2.2. Procedures

The participants were evaluated in two conditions: barefoot and with the customized inverted drop insoles. Each condition involved a sequence of standardized measurements of gait analysis (body positioning) and spinal curvatures (the tools are detailed in the sections below) (Figure 2).

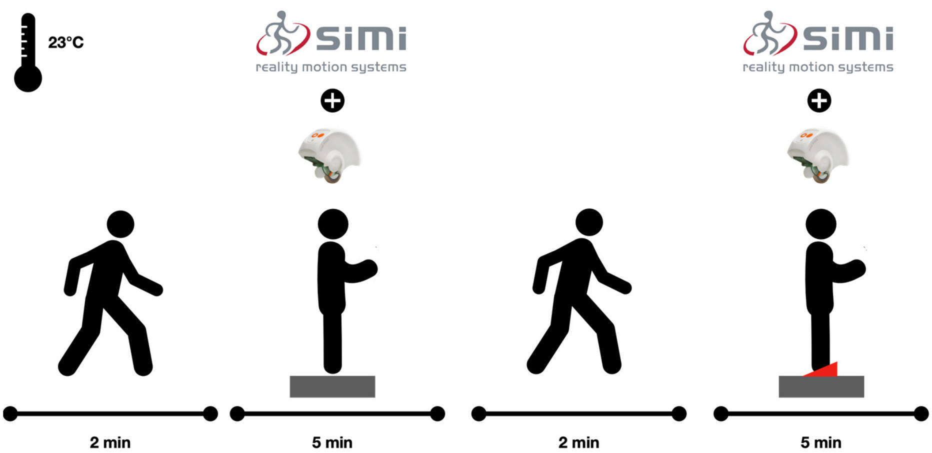

Figure 2. Experimental design: measurement of gait and body positioning with Simi Aktysis 3D system, and spinal curvatures with IDIAG 360® tool.

2.2.1. Assessment Protocol

1. In a room with a controlled temperature of 23 °C, participants were instructed to walk barefoot for 2 min.
2. Participants stood barefoot on a flat platform for an initial 5 min acclimation period, after which measurements were taken.
3. Subsequently, participants were instructed to walk barefoot for an additional 2 min.
4. After walking, participants stood on the customized insoles placed on the same platform for another 5 min period before the second set of measurements was taken.

2.2.2. Gait and Body Positioning Analysis

A Simi Aktysis 3D motion capture system (Simi Motion System, Unterschleißheim, Germany) [41] was used to record 3D kinematic data of body positioning, focusing on the sagittal plane. Reflective markers were placed on standard surface anatomical landmarks including the distal tendon of the deltoid muscle, the trochanter, the lateral femoral condyle, and below the lateral malleolus. The angles of trunk, hip, and knee were recorded (Figure 3).

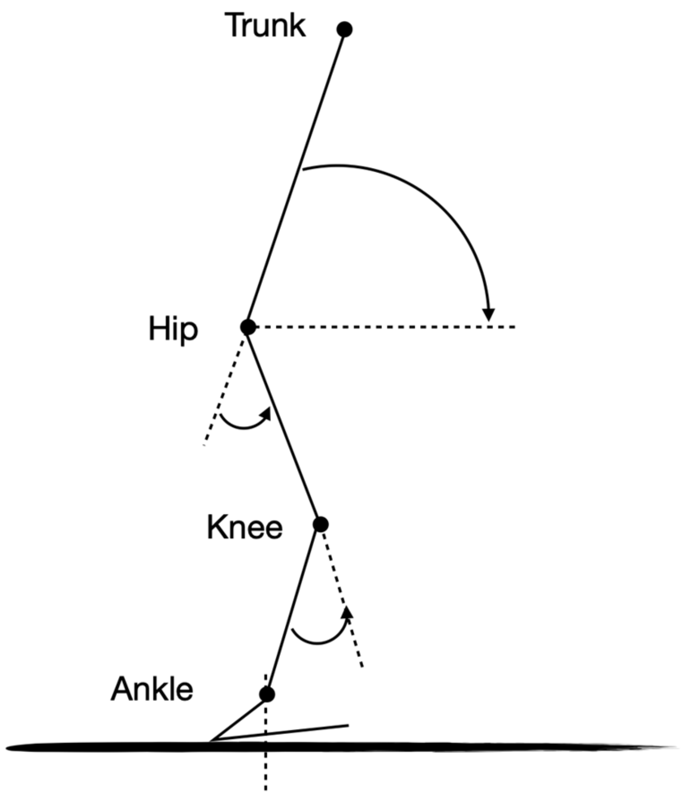

Figure 3. Segment and joint angle definitions are illustrated for the sagittal plane (*Note*: For each segment and joint angle, the arrow direction indicates the positive angle from neutral).

2.2.3. Spinal Curvature Measurement

Spinal curvatures (i.e., dorsal kyphosis, lumbar lordosis, and sacral slope) were evaluated using a non-invasive method with a Medi Mouse IDIAG 360® (MediMouse, Idiag AG, Fehraltorf, Switzerland) (Figure 4) [42,43]. This tool is a validated method that does not expose participants to radiation [42,44–46]. This system tracks participants' spinal shape (lordosis and kyphosis) and mobility in the sagittal plane by measuring postural changes over time. The IDIAG 360 measures sagittal curvature along the spinous processes in a static position using photoelectric sensors [42]. In this study, the device was positioned along the spinal processes to capture sagittal curvature changes between barefoot and insole conditions.

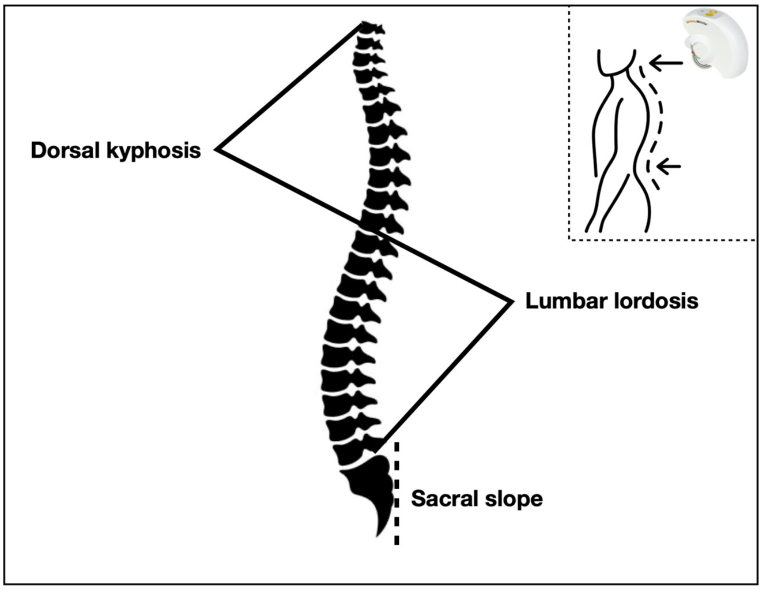

Figure 4. Spine angles automatically calculated with the IDIAG 360® tool [42,44–46].

2.2.4. Electromyographic (EMG) Activity

EMG activity of the *rectus abdominis* and *rectus femoris* muscles was recorded using the Bioplux® device with standard electrode placements. At the beginning of the protocol, participants were asked to perform a maximum voluntary contraction (MVC) of both muscles: the *rectus femoris* and the *rectus abdominis* (Figure 5(1)). These muscles were chosen for their roles in posture maintenance and lumbar stabilization, factors relevant to the management of LBP [47,48]. For the *rectus femoris*, the participants were asked to exert maximum knee extension force while seated on a chair with the knees in 90° of flexion, with a fixed isometric dynamometer placed on the ankle. For the *rectus abdominis*, the participants were seated and asked to perform maximum trunk flexion against the observer's forearm, which was positioned against the participant's chest. The evaluation protocol in both conditions included five five-second contraction intervals, with a five-second rest between each contraction (Figure 5(2)). The analyzed outcome was the average percentage of MVC across the five maximal contractions.

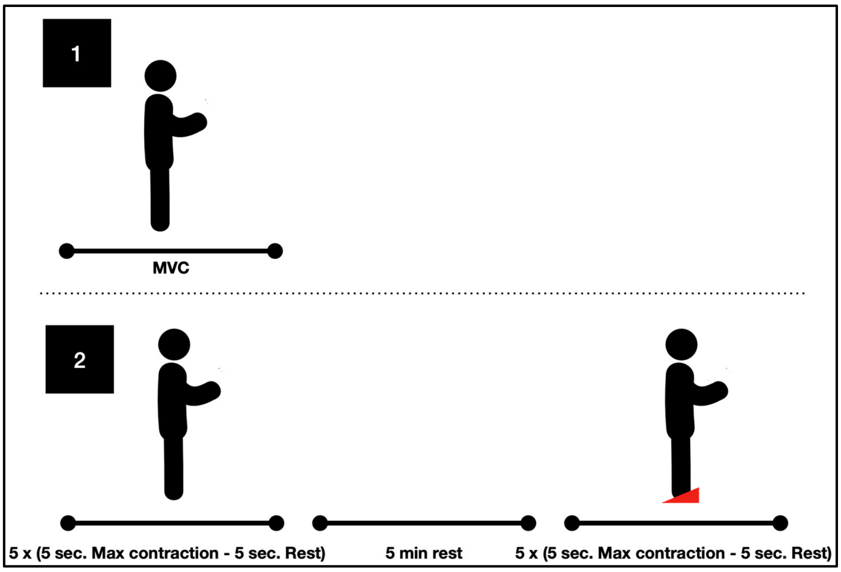

Figure 5. Experimental design: measurement of core muscle activation using Bioplux® device. (1) Maximum voluntary contraction (MVC); (2) repeated MVCs for the *rectus abdominis* and *rectus femoris* muscles.

2.3. Statistical Analysis

The data were tested for normality using the Shapiro–Wilk test, and homogeneity of variance was assessed with Levene's test. In cases of normal distribution, the results are presented as means ± standard deviation (SD), and group comparisons were performed using parametric tests. Not all variables were normally distributed. For non-normally distributed data, the results are reported as medians and interquartile ranges (IQRs), and comparisons were conducted using non-parametric tests. Therefore, the difference between the means for both conditions (i.e., barefoot (normal condition) or insole) was calculated with the paired samples t-test (noted as T) for normal samples, and for data that did not meet normality assumptions, the Wilcoxon test (noted as W) was applied, with the significance level set at $p < 0.05$. For parametric data, effect size (ES) was used to assess the magnitude of differences, classified according to Cohen's scale. The ES could be trivial (ES < 0.2), small (0.2 ≤ ES < 0.5), moderate (0.5 ≤ ES < 0.79), or large (ES ≥ 0.8). For nonparametric data, the magnitude of difference was assessed by the rank biserial correlation (rB), which can be considered an ES and is which serves as an effect size equivalent to the correlation coefficient. It was categorized as trivial (rB < 0.1), small (0.1 ≤ rB < 0.3), moderate (0.3 ≤ rB < 0.5), or large (rB ≥ 0.5). All analyses were performed with Jeffrey's Amazing Statistics Program (JASP Team, version 0.14.1, computer software).

3. Results

The socio-demographics, anthropometric characteristics, and pain ratings of the subjects are presented in Table 1.

3.1. Kinematics Parameters

3.1.1. Gait Analysis (Body Positioning)

The mean values and standard deviations (SDs), median values and interquartile ranges (IQRs), p-values, and effect size or rank biserial correlation of the trunk, hip, and knee angles under barefoot and inverted drop sole conditions recorded with the Simi Aktysis 3D system are presented in Figure 6.

For the trunk, the median [Q1–Q3] angle was −0.90 [−1.50–0.15] for the barefoot condition and −0.40 [−1.15–0.60] for the inverted drop sole condition. For the hip, the median [Q1–Q3] angle was −2.40 [−3.55–−1.55] in the barefoot condition and −2.40 [−3.25–−1.35] with the inverted drop sole. Thus, for the knee, the median [Q1–Q3] angle was −0.40 [−1.35–0.95] for the barefoot condition and 0.60 [−0.45–2.00] for the inverted drop sole condition.

Significant differences were observed in the trunk and knee angles (p = 0.009 and p < 0.001, respectively), with a moderate and large magnitude of difference (rB = −0.41 and rB = −0.96, respectively). No significant difference was noted for the hip angle (p = 0.162).

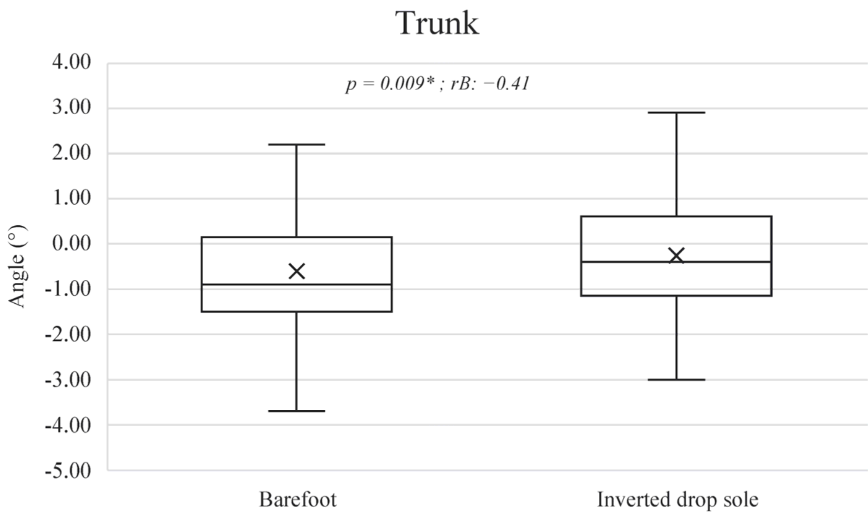

Figure 6. *Cont.*

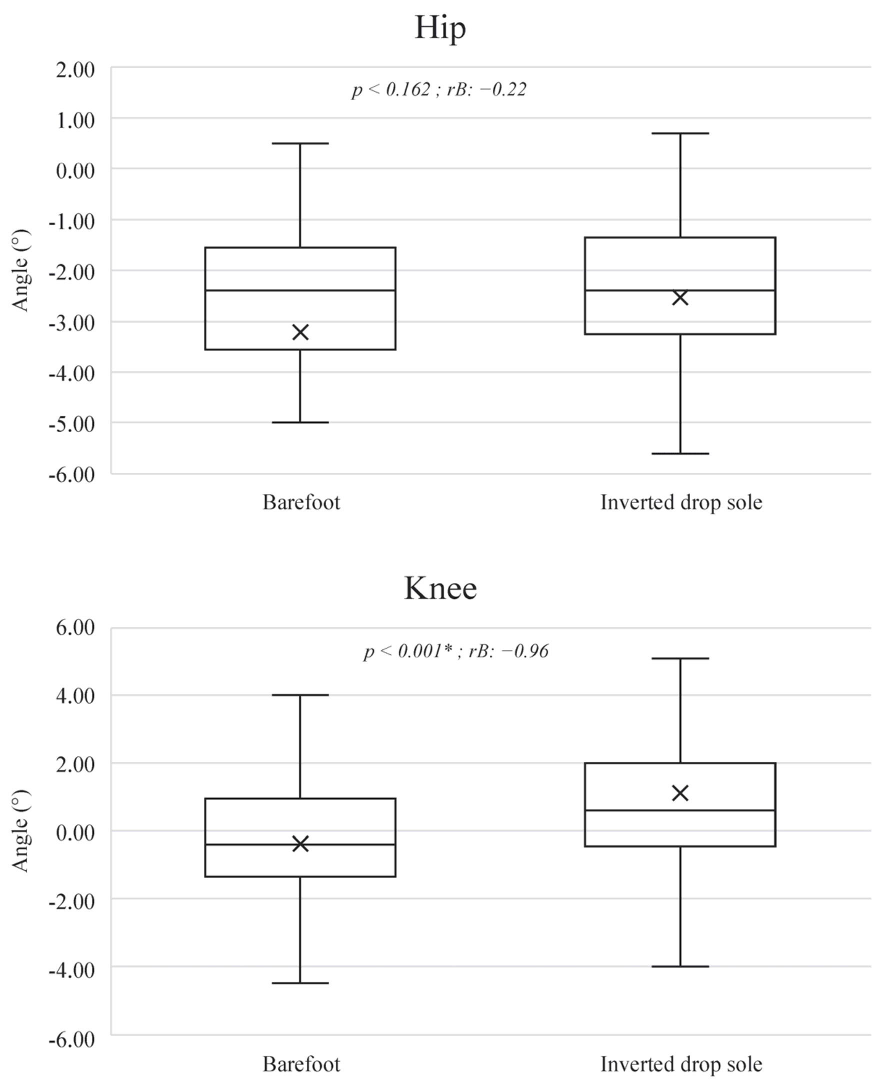

Figure 6. Boxplots for trunk, hip, and knee angles (°) under barefoot and inverted drop sole conditions. * Significant difference between two conditions ($p < 0.05$). ES: effect size; rB: rank biserial correlation. *Note*: Mean corresponds to the cross, median corresponds to the horizontal line, upper line of the box corresponds to the third quartile, lower line of the box corresponds to the first quartile, upper whisker corresponds to the mean + 1.96 standard deviation (SD) of the distribution, and lower whisker corresponds to the mean − 1.96 SD.

3.1.2. Spinal Curvatures

The mean values and standard deviations (SDs), median values and interquartile ranges (IQRs), *p*-values, and effect sizes or rank biserial correlation of spinal curvatures (i.e., 1. Dorsal kyphosis, 2. Lumbar lordosis, and 3. Sacral slope) under the barefoot and inverted drop sole conditions recorded with the Medi Mouse IDIAG 360 are presented in Figure 7.

For the sacral slope, the data were normally distributed. The mean angle was 14.96° ± 9.27° for the barefoot condition and 11.47° ± 9.04° for the inverted drop sole condition. For dorsal kyphosis, the median [Q1–Q3] angle was 47.0 [43.0–52.0] for the barefoot condition and 46.0 [39.0–51.0] for the inverted drop sole condition. Similarly, for lumbar lordosis, the median [Q1–Q3] angle was −29.0 [−36.0–−21.5] for the barefoot condition and −25.0 [−30.0–−18.0] for the inverted drop sole.

Significant differences were observed for the three spinal curvatures, dorsal kyphosis, lumbar lordosis, and sacral slope ($p < 0.001$, respectively), with a large magnitude of difference for dorsal kyphosis, lumbar lordosis, and sacral scope (rB = 0.71, rB = −0.94, and ES = 0.54, respectively).

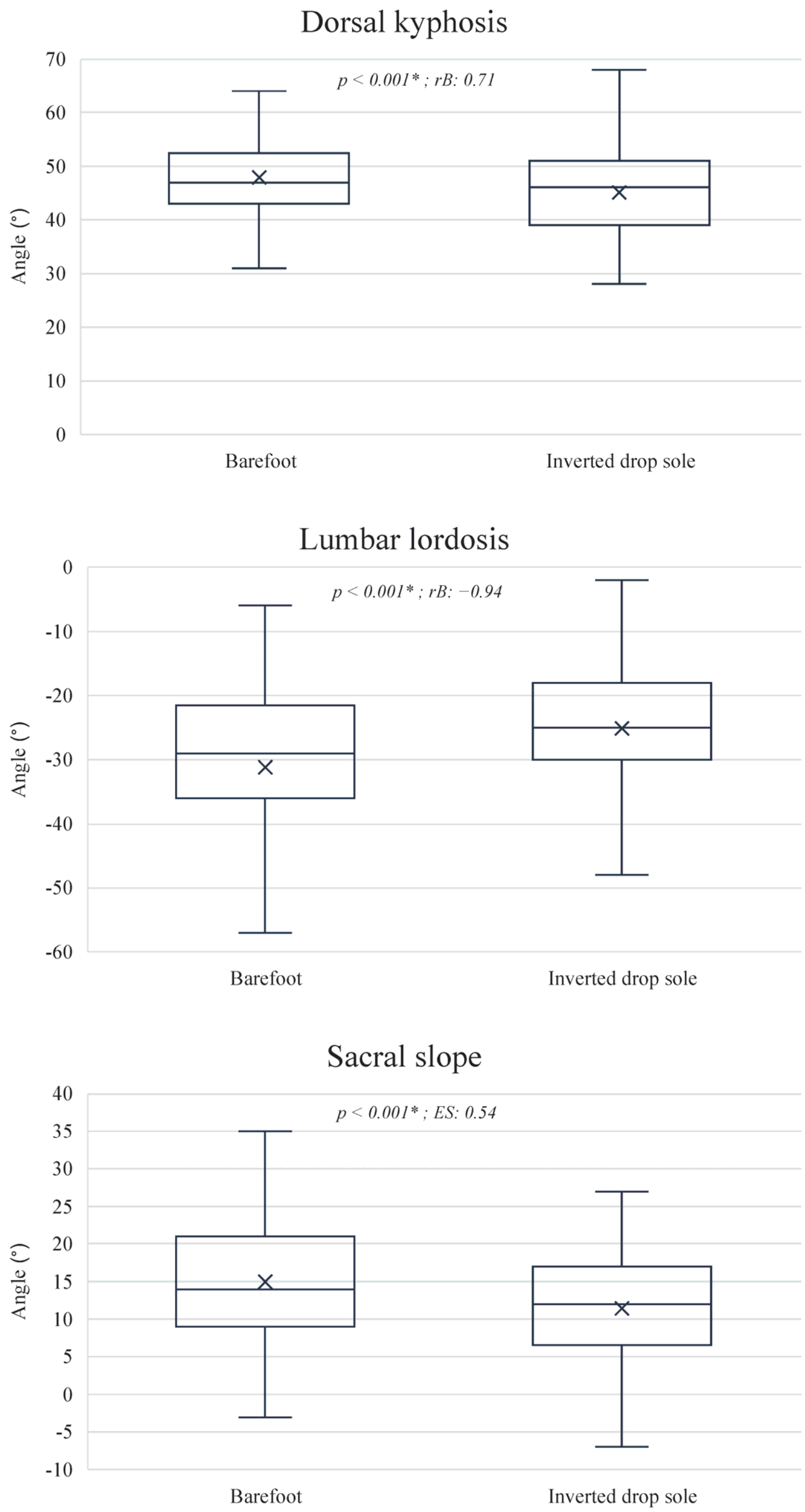

Figure 7. Boxplots for spinal curvature angles (°) under barefoot and inverted drop sole conditions. * Significant difference between the two conditions ($p < 0.05$). ES: effect size; rB: rank biserial correlation. *Note*: Mean corresponds to the cross, median corresponds to the horizontal line, upper line of the box corresponds to the third quartile, lower line of the box corresponds to the first quartile, upper whisker corresponds to the mean + 1.96 standard deviation (SD) of the distribution, and lower whisker corresponds to the mean − 1.96 SD.

3.2. Electromyographic Activities

The mean values and standard deviations (SDs), median and interquartile ranges (IQRs), *p*-values, and effect sizes or rank biserial correlation for EMG activities in % of MVC (i.e., *rectus abdominis* and *rectus femoris*) under the barefoot and inverted drop sole conditions recorded with the Bioplux® device are presented in Figure 8.

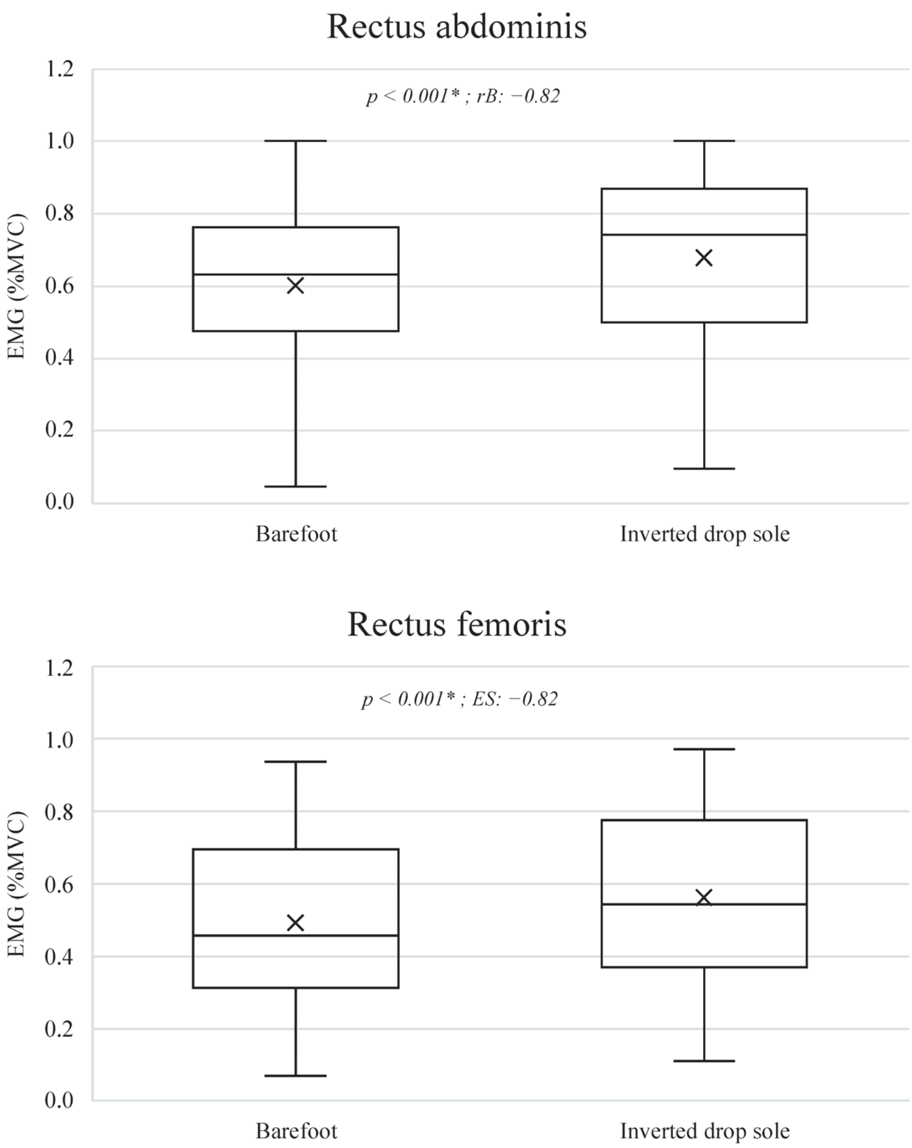

Figure 8. Boxplots for EMG activities (% MVC) under barefoot and inverted drop sole conditions for the *rectus abdominis* and *rectus femoris*. * Significant difference between the two conditions ($p < 0.05$). ES: effect size; rB: rank biserial correlation. *Note*: Mean corresponds to the cross, median corresponds to the horizontal line, upper line of the box corresponds to the third quartile, lower line of the box corresponds to the first quartile, upper whisker corresponds to the mean + 1.96 standard deviation (SD) of the distribution, and lower whisker corresponds to the mean − 1.96 SD.

For the rectus abdominis, the data were non-parametric. The median activation was 0.63 [0.48–0.76] %MVC for the barefoot condition and 0.74 [0.50–0.87] %MVC for the inverted drop sole condition. The rectus femoris activation, however, was normally distributed. The mean activation was 0.49 ± 0.24 %MVC for barefoot and 0.56 ± 0.24 %MVC for inverted drop sole conditions.

Significant differences were observed for the two muscles, namely, *rectus abdominis* and *rectus femoris* ($p < 0.001$, respectively), with a large magnitude of difference for both (rB = −0.82, and ES = −0.82, respectively).

4. Discussion

The aim of this study was to evaluate the effects of inverted drop soles (i.e., insoles with ankle dorsiflexion) on the sagittal posture, such as the kinematic parameters of the lower limbs (i.e., trunk, hip, and knee angles) and lower back (i.e., spinal curvature angles), and as well as EMG activities (i.e., *rectus abdominis* and *rectus femoris*). The findings demonstrated significant alterations in posture and muscle activation, indicating potential clinical benefits for individuals with LBP musculoskeletal disorders.

The results showed that the inverted drop sole significantly increased trunk and knee flexion. Indeed, wearing these shoes leads to a significant increase in trunk and knee flexion, by 0.33 and 1.49 degrees, respectively. According to the reports of several studies [28,49], the same trends concerning kinematics variables between the normal condition and negative-heel shoes were reported with an increase in knee and trunk flexion angles. Moreover, the results of this study also demonstrated a reduction in forward tilting of the pelvis. Specifically, significant modifications in spinal curvatures were observed, including a decrease in dorsal kyphosis, lumbar lordosis, and sacral slope angulation. According to the literature [50,51], similar trends were observed with the effects of negative-heel shoes, or inverted drop soles, revealing significant biomechanical changes, particularly in the tilting of the pelvis and spinal curvatures. Research by Li et al. indicates that negative-heel shoes can decrease lumbar lordosis, thereby promoting a more neutral spinal posture [51].

Considering the principles of podiatry, it is well known that the foot is the first body segment to encounter the ground, playing a vital role in bearing weight, directing gait, and supporting the body [52,53]. By modifying the inclination of the foot, specifically through dorsiflexion achieved by wearing inverted drop soles or similar footwear (i.e., shoes that position the toe higher than the heel), a chain reaction occurs, significantly altering the angles of the knee and trunk joints. This results in increased trunk and knee flexion and aligns the spinal column by reducing kyphosis and lumbar curvatures [50]. These biomechanical changes and their associated effects have also been explored in previous studies [29,50,54–58]. This configuration, which involves ankle dorsiflexion, promotes a backward shift of the center of gravity, thereby decreasing lumbar lordosis and modifying overall spinal alignment [51].

Kinematic parameters, such as lower limb joint angles and spino-pelvic parameters, can be altered with foot tilt. Although the objectives of this study differ from research on foot pronation, which is characterized by the adduction and plantar flexion of the talus and eversion of the calcaneus [59], some studies have reported an increase in the sacral angle, lumbar lordosis, and thoracic kyphosis when tilting the foot inward (i.e., to 10°) in a bipedal static position [54,55]. Other research has highlighted the relationship between pelvic tilt and lumbar lordosis [33,34] and the connection between hip extension and standing posture [60]. These findings establish a clear link between foot positioning (i.e., podal orientation) and the posture of the lower limbs, pelvis, and spine [50,54–58], confirming that the postural regulation system can be adjusted along the medio-lateral axis based on pelvic tilt.

In this context, the changes in spinal alignment observed in this study—specifically the reduction in dorsal kyphosis, lumbar lordosis, and sacral slope curvatures—can be attributed to modifications in the kinematic parameters of the lower limbs when wearing shoes with an inverted drop sole [29,50]. These findings suggest that such footwear could represent a potentially promising approach to preventing musculoskeletal disorders or back injuries, such as LBP, which are often linked to poor posture.

The reduction in lumbar lordosis observed in this study suggests that ankle dorsiflexion may help counteract anterior pelvic tilt, a well-known risk factor for increased lumbar curvature and LBP. It is well established in the literature that an anteverted pelvis leads to an increase in sacral slope, consequently raising lumbar lordosis [35,36]. Increased lordosis exerts compressive forces on the posterior part of the spine, impacting vertebral structures [37,61]. The findings of this present research align with studies indicating that modifying spino-pelvic parameters through postural adjustments can reduce strain on vertebral structures and improve spinal alignment [35,37,61,62]. The observed reduction in dorsal kyphosis further supports the idea that foot positioning plays a critical role in spinal curvatures, offering potential therapeutic benefits in preventing spinal deformities and managing LBP [54,55].

Moreover, the results align with previous research indicating that dorsiflexion footwear alters lower limb biomechanics and spinal alignment by shifting the center of pressure forward, which engages different muscle recruitment patterns [27,29,63]. Specifically, the results showed a significant increase in the EMG activity (in % of MVC) for the rectus abdominis and rectus femoris, two muscles essential for postural balance [64]. The EMG analysis revealed a 17.46% increase in rectus abdominis activation and a 14.29% increase in rectus femoris activation. Previous studies, such as Bourgit et al., have reported a general trend of increased *tibialis anterior* activity during dorsiflexion, especially during fitness exercises, walking, and running compared to normal footwear [27]. Similarly, Li and Hong observed a significantly larger integrated electromyographic value, longer duration of EMG activity, and higher mean amplitude in the *tibialis anterior*, lateral gastrocnemius, and biceps femoris muscles [28]. However, no significant differences in EMG measurements were found in the rectus femoris and rectus abdominis muscles between normal sport shoes and negative-heeled shoes during treadmill walking [28]. The differences in activation could be attributed to variations in the type of exercise between studies involving footwear or insoles with ankle dorsiflexion [27,28].

The increased muscle activation observed in this study could be explained by the body's need to maintain postural balance when tilting backward. As the body tilts, several muscle groups work in coordination to counteract the force of gravity and restore an upright position [47,48]. In the case of inverted drop soles, the *rectus abdominis*, located at the front of the abdomen, is activated to stabilize and support the spine, particularly the lumbar region. The contraction of the abdominal muscles increases intra-abdominal pressure, which helps maintain the upright position of the trunk and prevent excessive lumbar hyperextension. The enhanced activation of the *rectus abdominis*, a key core stabilizer, suggests that insoles with ankle dorsiflexion could be beneficial in therapeutic settings where spinal support is critical [47,48]. Additionally, the *rectus femoris*, located at the front of the thigh, contributes to stability and balance [47,48]. When contracted, it assists in maintaining hip extension, which is crucial for stabilizing the body when standing. Therefore, in this study, both the rectus abdominis and rectus femoris were more activated during dorsiflexion to restore balance when the body leans backward, realigning the body's center of gravity and counterbalancing gravitational forces to regain and maintain an upright posture [47,48].

It is important to note that the results of this study were obtained under different conditions compared to previous studies, which were typically conducted during treadmill walking [28,49] or fitness exercises, walking, and running [27]. Due to the limited research on this specific topic, it is difficult to find studies that exactly match the parameters and test conditions used in this study.

Despite the promising findings, this study had some limitations. The small sample size and wide age range limit the generalizability of the results, highlighting the need for studies with more homogeneous samples. Further research is necessary to expand our understanding of the effects of this type of shoe or insole. Future studies should incorporate dynamic assessments to explore the impact of insoles during walking and daily activities. This would provide a more comprehensive understanding of their effect on postural stability in real-life conditions. One of the limitations of this study is the reliance on static kinematic analyses. The literature suggests that both static and dynamic evaluations should be conducted within orthopedic treatment contexts to examine the differences between these two conditions and their interactions with the musculoskeletal system. This approach would enable the development of tailored solutions for individual patients [65–67]. Therefore, continued research in this direction would be valuable to better understand these interactions. Research could also explore the specific neuromuscular and biomechanical changes associated with different types of negative-heel insoles, and examine their impact on various subpopulations of LBP patients. Future studies could benefit from a more detailed examination of the different types of lumbar lordosis, as each type reflects a specific pattern within the spino-pelvic complex. Research has identified four distinct types of lumbar lordosis in asymptomatic adults, categorized based on sacral slope values [36]. A deeper understanding of these variations could offer insights into how different lordotic patterns affect posture, biomechanics, and musculoskeletal health, providing valuable information for clinical interventions. Exploring the combined effects of these insoles alongside other conservative treatments, such as physical therapy and exercise, could offer a more comprehensive understanding of their potential role in the management of LBP.

5. Conclusions

The objective of this study was to analyze the effects of an inverted drop sole on sagittal posture, focusing specifically on the kinematic parameters of the lower limbs, spinal curvatures, and EMG activities. This study demonstrates that inverted drop sole insoles, designed to promote ankle dorsiflexion, can significantly alter sagittal posture by reducing dorsal kyphosis and lumbar lordosis, as well as modifying knee and trunk kinematics. These postural adjustments may offer a non-invasive approach to managing LBP, emphasizing the importance of footwear in musculoskeletal health. Although promising, further research is needed to establish the long-term efficacy and clinical relevance of negative-heel insoles in diverse populations of LBP patients.

Author Contributions: Conceptualization, M.R.e.S. Writing—review and editing, M.R.e.S. and L.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Myalgia Clinics (5 May 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

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