JOURNAL OF SPORTS AND PHYSICAL ACTIVITY
2025.VOL 1, NO 2, (94-107)
https://www.jospa.spdfharmony.com/index.php/jospa/index
DOI: https://doi.org/10.64268/jospa.v1i2.15

Lumbar alignment: Its role on plantar pressure and postural sway in people with low back pain

Harem Abdalqadir Mohammed[1 2], Ali Yalfani[2], Dara Latif Saifalddin[1], Saiwan Sirwan Mohammed[1], Hiwa Ahmed Rahim[1*]

[1]University of Halabja, IRAQ
[2]Bu-Ali Sina University, IRAN

ABSTRACT

Background: Low back pain (LBP) is a global health concern influenced by biomechanical factors, including lumbar alignment. Altered lumbar curvature (hyperlordosis/hypolordosis) may disrupt posture, plantar pressure distribution, and postural stability, contributing to LBP pathophysiology. **Aim:** This study investigated the impact of lumbar alignment on plantar pressure patterns and postural sway in individuals with LBP. **Methods:** Thirty-six participants (18–25 years) were categorized into hyperlordosis, hypolordosis, and normal lordosis groups. Lumbar curvature was measured using a flexible ruler, while plantar pressure and center of pressure (COP) parameters were assessed via the Zebris FDM-S platform during bipedal and unipedal standing. Statistical analysis included ANOVA and Tukey's post hoc tests (SPSS v26, $p<0.05$). **Results:** The normal lordosis group exhibited significantly smaller COP confidence ellipse parameters (minor/major axis length, area) and lower postural sway compared to hyperlordosis and hypolordosis groups ($p<0.05$). Anterior-posterior plantar pressure asymmetry was pronounced in hyperlordosis (anterior shift) and hypolordosis (posterior shift). No significant differences were observed in mediolateral COP displacement or bilateral foot symmetry ($p>0.05$). **Conclusion:** Normal lumbar alignment enhances postural stability and balanced plantar pressure distribution, whereas hyperlordosis and hypolordosis correlate with increased postural fluctuations and asymmetric foot loading. Rehabilitation strategies targeting lumbar alignment may improve biomechanical outcomes in LBP management.

To cite this article: Mohammed, H. A., Yalfani, A., Saifalddin, D. L., Mohammed, S. S., & Rahim, H. A. (2025). Lumbar alignment: Its role on plantar pressure and postural sway in people with low back pain. *Journal of Sports and Physical Activity, 1*(2), 94-107. https://doi.org/10.64268/jospa.v1i2.15

ARTICLE HISTORY

Received: July 17, 2025
Revised: August 6, 2025
Accepted: Oct 10, 2025

KEYWORDS

Low back pain;
Lumbar alignment;
Plantar pressure;
Postural sway;
Biomechanics.

INTRODUCTION

Low back pain (LBP) is a common worldwide health issue that affects people from different demographic groups. The multiple nature of this entails an intricate interaction of musculoskeletal, neurological, and biomechanical components (Tanwar, 2022). Of all these factors, the alignment of the lumbar spine is critical because it plays a crucial role in maintaining proper posture and movement mechanics (Shah, 2019). Gaining knowledge about the connection between the alignment of the lower back and factors like how pressure is distributed on the feet and how the body's posture

Correspondent Author: Rahim, H. A., University of Halabja, IRAQ hiwa.rahim@uoh.edu.iq

sways could offer a valuable understanding of the underlying causes of LBP and help guide treatments aimed at reducing discomfort (Sainz, 2017).

The lumbar spine connects the upper body and lower limbs, enabling effective weight transfer, stability, and movement during everyday tasks (Ngiejungbwen, 2024). Deviating from appropriate lumbar alignment can disrupt the delicate balance of forces operating on the spine and surrounding structures (Mizrahi, 2015). Structural abnormalities, muscle imbalances, or functional inadequacies can cause this. Consequently, individuals suffering from LBP frequently have alterations in their lumbar alignment, including excessive lordosis, kyphosis, or lateral curvature. These changes can exacerbate the discomfort and impede the performance of daily activities (Gallagher, 2014).

Plantar pressure distribution is an essential factor in the biomechanical function related to LBP. With its intricate composition, the foot has a vital function in absorbing impact, ensuring stability, and enabling movement during walking and weight-bearing tasks (Ngiejungbwen, 2024). Several musculoskeletal conditions, such as LBP, have been linked to irregularities in how pressure is distributed on the soles of the feet. (Alias, 2020). This highlights the significance of evaluating foot mechanics in people with spinal problems (Branthwaite, 2015). By clarifying the connection between the alignment of the lower back and the patterns of pressure on the soles of the feet, researchers can get helpful knowledge on the biomechanical processes that contribute to LBP and the resulting abnormalities in walking and posture (Smith, 2022).

Postural sway refers to the little movements of the body's center of mass inside the base of support (Ivanenko, 2018). It is an essential part of balance control and neuromuscular function. People with LBP often show changes in their postural sway characteristics, which indicate problems with how their senses and muscles work together to maintain balance and coordination (Koch, 2019). Studying the relationship between lumbar alignment and postural sway parameters can offer essential knowledge about the causes of balance problems in people with LBP (Kripa, 2021). This information can help develop specific rehabilitation techniques that enhance postural control and minimize the risk of falling (Dewar, 2015).

The interplay between lumbar alignment, plantar pressure distribution, and postural sway in persons with LBP is of great therapeutic importance due to the intricate interconnections among these factors (Bitenc-Jasiejko, 2020). By clarifying the fundamental biomechanical processes that connect these elements, scientists can improve our comprehension of the pathophysiology of LBP and contribute to the creation of more efficient methods for diagnosis and treatment (Urits, 2019).

Numerous investigations have explored the connection between lumbar alignment and plantar pressure or postural sway, with most indicating a biomechanical link between spinal posture and these factors (Hmida, 2023). Nonetheless, most research has focused on these elements in isolation, yielding predominantly descriptive findings and neglecting their possible combined interaction in individuals experiencing LBP. This study aims to fill this void by examining the interrelationship among lumbar alignment, plantar pressure distribution, and postural sway within a unified framework. Such a methodology may provide a more thorough understanding of the biomechanical processes that contribute to LBP and facilitate the creation of more precise diagnostic and rehabilitative approaches. Consequently, this research aims to assess the influence of lumbar alignment on plantar pressure distribution and postural sway in individuals suffering from LBP.

METHOD

Study Design

This study is a laboratory investigation that examines three groups of participants with low back pain: hyperlordosis, hypolordosis, and normal lordosis. The study design analyzes data from several groups of individuals with varying degrees of curvature in their lower back.

Attendees

The study sample comprised young adults between 18 and 25 who were students at Bu-Ali Sina University in Hamedan, Iran. We utilized (G*Power 3.1.9.7) software to determine the sample size, and based on the convenience sampling approach, we opted for a total of 36 participants, considering all relevant study criteria. Of these, 12 individuals had hyperlordosis, 12 exhibited hypolordosis, and 12 exhibited normal lordosis. The participants for this study were chosen following their completion of the required examinations.

Criteria for Inclusion

The patient has no previous medical history of surgical procedures, bone fractures, burns, neuromuscular disorders, significant injuries, or trauma to the spine, lower limbs, or joints (such as disc herniation, osteoarthritis, rheumatoid arthritis, etc.). Additionally, there is no indication of using prosthetic limbs in the thigh, knee, or ankle. The individual has not previously utilized any orthotics or therapeutic footwear. There is no record of the individual having diabetes or peripheral nerve disorders. The spine's alignment in the thoracic, cervical, pelvic, and lower extremities is normal. There is no presence of scoliosis in the spine.

Criteria for exclusion

Individuals experiencing chronic low back pain of unknown origin lasting longer than three months. Per the physician's assessment, individuals experience low back pain due to a particular pathology.

Data Collection

The participants' height, weight, and BMI were assessed using a Seca electronic scale model BS100, with measurements recorded in centimeters for height, kilograms for weight, and kilograms per square meter for BMI. The lumbar lordosis curve was measured using a flexible ruler and computed using a specific mathematical equation. The pain severity was evaluated using the Visual Analog Scale (VAS). The Zebris FDM-S Foot Pressure Platform was used to record foot pressure data. The participant's dominant foot was ascertained by instructing them to kick a soccer ball.

Procedure

Once the participants were identified, screened, and confirmed, they proceeded to the sports rehabilitation laboratory in the Faculty of Art and Architecture at Bu-Ali Sina University. Upon entering the laboratory, the volunteers perused and affixed their signatures to the written informed consent form. We explained the test methods clearly and concisely to the participants. Before conducting the tests, the participants engaged in a 6-minute warm-up session consisting of 3 minutes of ergometer warm-up at a consistent pace and 3 minutes of overall stretching. We collected foot pressure measurements throughout bipedal and unipedal standing, with participants maintaining both open and closed eye conditions. The experiments were conducted for 30 seconds.

Data Analysis

The Win FDM-S stance software (version 01.02.09) was utilized to evaluate the foot pressure data. This study investigated the minor axis length, primary axis length, range of fluctuations, and angle between Y and the central axis of the 95% confidence ellipse. Additionally, the study examined COP displacement factors such as COP path length, COP displacement velocity, COP displacement in the medial-lateral direction, and COP displacement in the anterior-posterior direction. Furthermore, the study analyzed the percentage of force distribution in the forefoot and rearfoot, as well as the symmetry index. The symmetry index between the two feet was computed using the following formula: The formula to calculate the SI (Symmetry Index) is as follows: $SI = (R-L)/(R+L) \times 100$.

A value of 0.5 signifies perfect symmetry between the feet; $SI > 0.5$ shows a more significant proportion of force in the left foot, and $SI < 0.5$ suggests a more substantial proportion in the right foot. The device's instructions state that the recommended force ratio is 66 to 33 (33/66) for the rearfoot and forefoot. This ratio was also determined using $SI = (F-B)/(F+B) \times 100$. A value of 0.33 for the SI shows an optimal force distribution between the forefoot and rearfoot. An SI value less than 0.33 suggests an increase in force on the forefoot, while an SI value greater than 0.5 suggests an increase in force on the rearfoot. In all instances, we quantified the force as a percentage of the person's body weight.

Statistical Analysis

Data analyses were performed with the SPSS statistical software version 26.0 (SPSS Inc., Chicago, Ill., USA) and GraphPad Prism 9.1 (GraphPad Software Inc., San Diego, CA, USA). Results were analyzed by one-way analysis of variance (ANOVA) across the different experimental conditions. When ANOVA found a significant P value, Tukey's post hoc test demonstrated differences between the means. The minimal significance level was adopted, P<0.05, and data were expressed as the mean ± standard error of the mean (SEM).

RESULTS AND DISCUSSION

Results

Individual Information about the Subjects in the Research

The individual information of the subjects in this study is given in Table 1. The arch index is the sole region where the three groups exhibit substantial differences.

Table 1. Demographic Characteristics of the Subjects Present in the Research Groups

Group	Number	Age (years)	Height (cm)	Weight (kg)	Lumbar curvature	Pain level
Hyperlordosis	12	25.30±2.12	170.14±9.07	67.12±79.44	46.5±50.77	5.1±90.61
Hypolordosis	12	22.1±33.49	172.02±72.03	65.11±80.82	15.2±41.59	4.1±60.27
Normal	12	22.2±58.02	175.8±58.35	61.11±25.29	29.5±91.31	5.178±62
P		0.226	0.739	0.395	P<0.0001[abc]	0.081

(a) means a significant difference between the hyperlordosis and hypolordosis groups, (b) means a significant difference between the hyperlordosis group and the standard group, (c) means a significant difference between the normal and hypolordosis groups,

Comparative Analysis of the Center of Pressure Variability and Plantar Pressure Symmetry in the Study Group during Standing

Table 2 displays the average and variability of the COP swing indices, encompassing minor axis length, main axis length, range of motion, path length, swing speed, medial displacement, and anterior-posterior displacement. The measurements were conducted standing with both legs in three distinct groups: hyperlordosis, hypolordosis, and normal lordosis. The Shapiro-Wilk test results indicated that the data about the pressure applied to the soles of the feet while standing conform to a normal distribution (P > 0.05). The study examined the average and variability of plantar pressure symmetry indices in three groups: hyperlordosis, hypolordosis, and normal lordosis. These indices quantify the degree of symmetry between the left and right legs and the anterior-posterior symmetry of each leg. Measurements were conducted while standing upright with both legs.

Table 2. Parameters of Plantar Pressure while Standing

Indicators related to the 95% confidence ellipse			
Variable	**Hyperlordosis**	**Hypolordosis**	**Normal lordosis**
Minor axis length (mm)	14.3 ± 53.43	14.3 ± 83.51	10.2 ± 92.92
Major axis length (mm)	24.5 ± 59.95	25.4 ± 33.74	17.3 ± 82.93
Area of variation (mm^2)	230.47 ± 85.15	345.133 ± 50.02	114.37 ± 77.80
COP sway indices			
COP path length (mm)	253.47 ± 85.17	320.128 ± 50.24	173.61 ± 10.65
COP displacement velocity (mm/s)	16.6 ± 50.07	15.5 ± 51.40	12.3 ± 30.06
Medio-lateral displacement (mm)	17.7 ± 66.16	13.2 ± 90.54	15.4 ± 20.59
Anterior-posterior displacement (mm)	23.6 ± 50.32	19.4 ± 74.30	19.4 ± 36.12
Symmetry index			
Right and left foot	0/0±48/11	0/0±49/04	0/0±47/11
Front and back of the right foot	0/0±69/19	0/0±17/06	0/0±31/12
Front and back of the left foot	0/0±62/15	0/0±18/06	0/0±31/05

Comparative Analysis of the Length and Range of Motion of the Spinal Axis in the Study Groups

The findings along the minor axis indicate a statistically significant difference between the three groups [F(2,33) = 7.928, P = 0.002]. We conducted Tukey's multiple comparison test to examine the minor axis length in three groups. The normal lordosis group's minor axis length was considerably shorter than the hyperlordosis and hyperlordosis groups (Figure 1A; P = 0.006 and 0.003).

The findings revealed a statistically significant difference among the three groups [F = 8.39 (P = 0.001, 2, 33)]. We conducted Tukey's multiple comparison test to examine the significant axis length in three groups. The regular lordosis group exhibited a shorter primary axis length than the hyperlordosis and hypolordosis groups (Figure 1B; P = 0.006 and 0.002, respectively). The findings on the range of motion indicate a statistically significant difference among the three groups [F(2,33)=18.65, P = 0.001]. Tukey's multiple comparison tests revealed substantial variations in the range of motion among three groups: standard, hyperlordosis, and hypolordosis (Figure 1C; P = 0.011, 0.013, and 0.001).

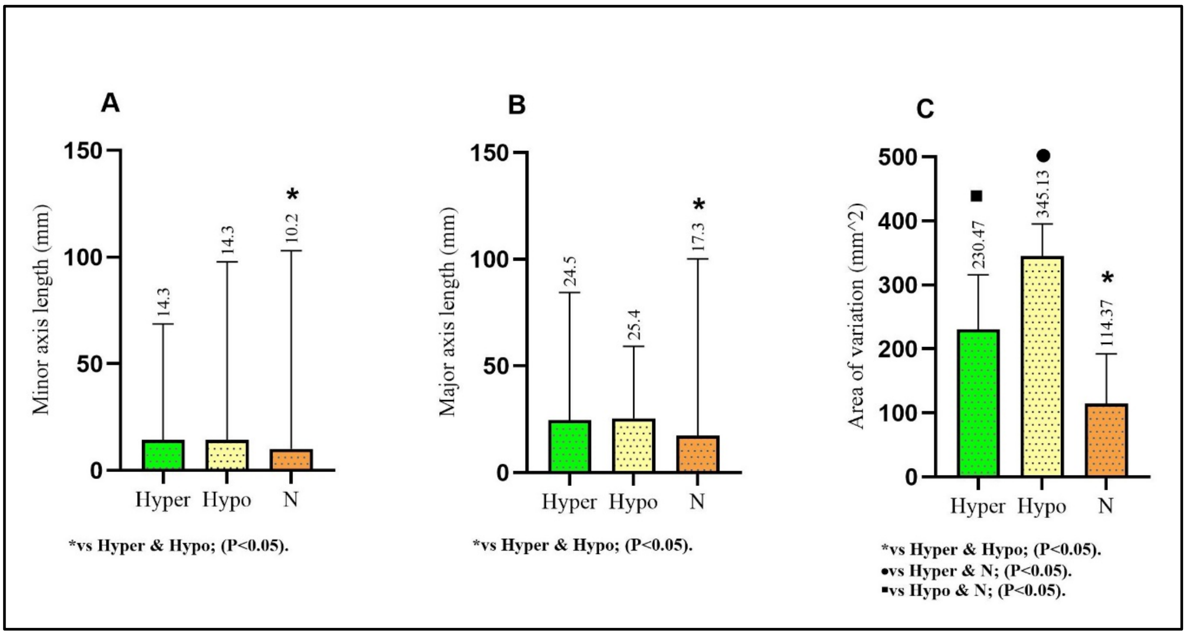

Figure 1. Results of one-way ANOVA on the indices of the 95% confidence ellipse. Abbreviations: Hyperlordosis, Hyper; Hypolordosis, Hypo; Normal, N.

Comparative Analysis of Postural Stability Parameters

The analysis of COP route length in three groups revealed a statistically significant variation across the groups [F(2,33) = 8.727, P = 0.001]. The group with normal lordosis showed a considerable difference compared to the group with hypolordosis (Figure 2A; P = 0.001), as indicated by Tukey's multiple comparison test for COP path length in the three groups. The analysis of the COP movement speed in the three groups revealed no statistically significant difference [F(2,33) = 2.295, P = 0.117]. (see Figure 2B). The results of mediolateral displacement in the three groups indicated no statistically significant difference between the groups [F(2,33) = 1.665, P = 0.205]. (see Figure 2C). The analysis of anteroposterior displacement in the three groups revealed no statistically significant difference between them [F(2,33) = 2.488, P = 0.099]. (See Figure 2D).

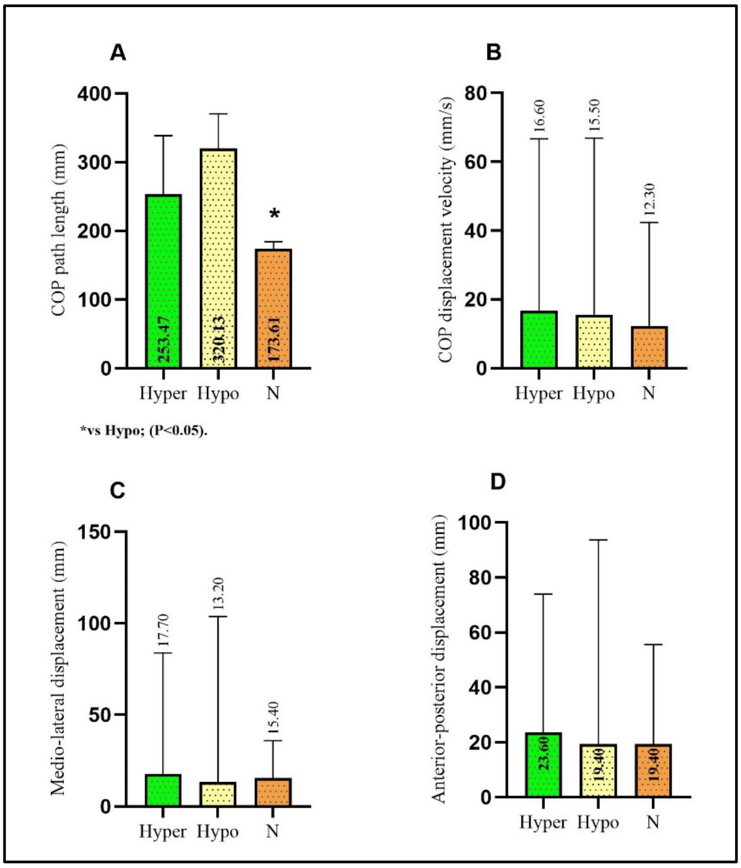

Figure 2. Results of One-Way ANOVA on the COP Sway Indices
Abbreviations: Hyperlordosis, Hyper; Hypolordosis, Hypo; Normal, N.

Bilateral Leg Pressure Symmetry Maintained Amidst Anterior-Posterior Disparities Across Three Groups

The analysis of pressure symmetry between the left and right legs revealed no statistically significant variation among the three groups [$F(2,33) = 0.139$, $P = 0.871$]. (see Figure 3A). The analysis of the anterior-posterior pressure symmetry of the right leg revealed a notable disparity among the three groups [$F(2,33) = 43.76$, $P = 0.001$]. Significant variations in the anterior-posterior pressure symmetry of the right leg were seen among the three groups (Figure 3B; $P = 0.001$). The hyperlordosis group had a considerable distinction from the other two groups. The analysis of left leg anterior-posterior pressure symmetry revealed a substantial disparity among the three groups [$F(2,33) = 58.40$, $P = 0.001$]. Tukey's multiple comparison tests revealed significant differences in left foot anterior-posterior pressure symmetry across all three groups (Figure 3C; $P = 0.001$, 0.001, and 0.008).

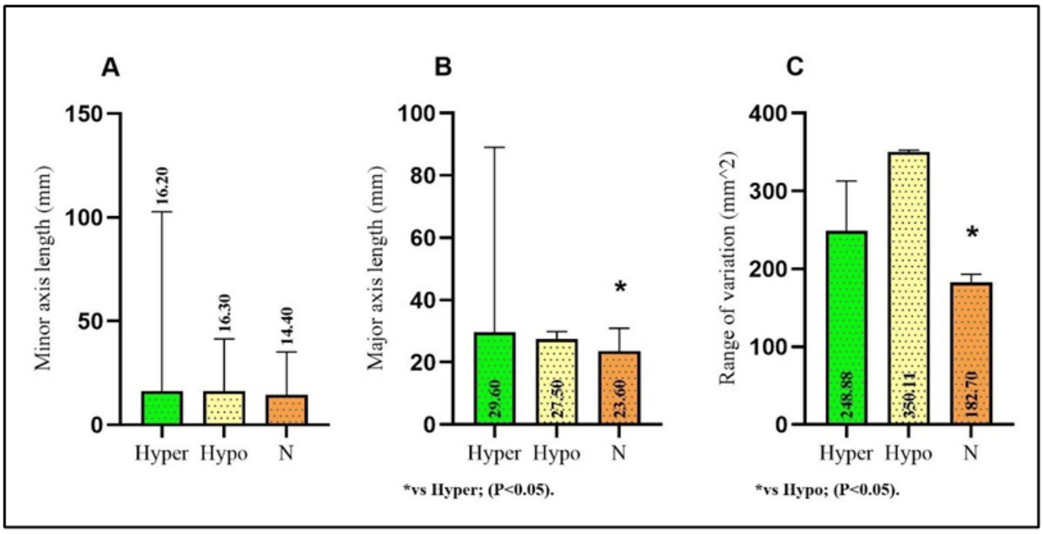

Figure 3. Results of One-Way ANOVA on the 95% Confidence Ellipse Indices
Abbreviations: Hyperlordosis, Hyper; Hypolordosis, Hypo; Normal, N.

Comparison of COP Oscillation Dynamics and Pressure Symmetry in Hyperlordotic, Hypolordotic, and Normal Lordotic Individuals During Unilateral Stance

Table 3 presents the average and variability of the COP oscillation parameters, encompassing the secondary axis length, main axis length, oscillation amplitude, oscillation path length, oscillation speed, middle displacement, anterior-posterior displacement, and the average and variability of the floor pressure symmetry indices. The leg, exhibiting both anterior and posterior symmetry of the dominant leg, is depicted in three categories: hyperlordosis, hypolordosis, and normal lordosis, while in a unilateral standing posture.

Table 3. Parameters of Plantar Pressure during Single-Leg Standing

COP Sway Parameters			
Variables	**Hyperlordosis**	**Hypolordosis**	**Normal lordosis**
Minor axis length (mm)	16.2±86.50	16.3±25.09	14.4±20.80
Major axis length (mm)	29.6±59.44	27.5±02.38	23.6±07.32
Range of variation (mm^2)	248.88±64.06	350.111±02.48	182.70±10.55
plantar pressure			
COP path length (mm)	298/135+77/41	341/113±69/96	312/115±11/42
COP displacement velocity (mm/s)	23/7±60/90	25/5±97/33	16/4±47/66
Medio-lateral displacement (mm)	21/6±01/57	17/3±24/90	18/3±53/67
Anterior-posterior displacement (mm)	25/5±16/58	21/3±40/65	23/3±70/43
Symmetry index			
Anterior and posterior pelvic tilt	0/0±69/19	0/0±19/08	0/0±31/12

Significant Differences in Primary Axis Length and Swing Amplitude during Single-Leg Standing among the Study Groups

The measurements of the minor axis length in the one-leg standing posture did not reveal any statistically significant differences among the three groups [F(2,33) = 1.792, P = 0.182]. (see Figure 4A). The one-leg standing posture analysis of the central axis length revealed a statistically significant difference among the three groups [F(2,33) = 3.5, P = 0.042]. Tukey's multiple comparison tests showed a statistically significant difference in the length of the central axis between the hyperlordosis group and the standard group (Figure 4B; P = 0.034).

The analysis of swing amplitude during single-leg standing revealed a statistically significant distinction among the three groups [F(2,33) = 7.160, P = 0.003]. Tukey's multiple comparison test showed a significant difference in oscillation amplitude between the hypolordosis and standard groups (Figure 4C; P = 0.002).

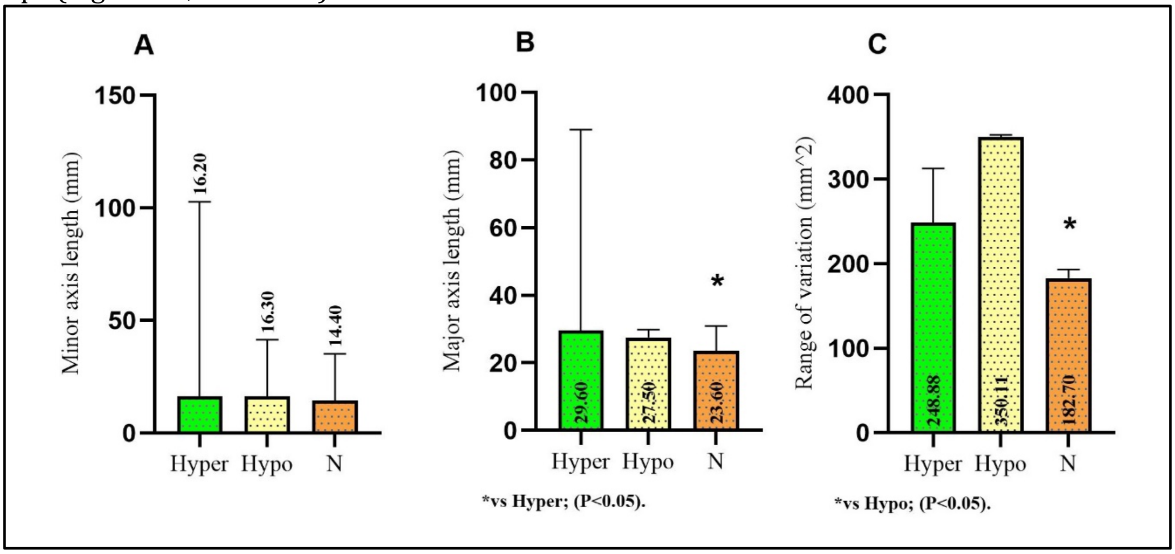

Figure 4. Results of One-Way ANOVA on the 95% Confidence Ellipse Indices
Abbreviations: Hyperlordosis, Hyper; Hypolordosis, Hypo; Normal, N.

Differential Effects of Lumbar Lordosis on Postural Control

The analysis of the swing path length during one-legged standing revealed no statistically significant variation among the three groups [F(2,33) = 0.324, P = 0.726]. (Refer to Figure 5A). The findings of the COP displacement speed during single-leg standing revealed a statistically significant difference among the three groups [F(2,33) = 7.804, P = 0.002]. Significant disparities in the rate of COP displacement were seen between the groups with hyperlordosis and normal lordosis and between the groups with hypolordosis and normal lordosis (Figure 5B; P = 0.020 and 0.002). The analysis of mediolateral displacement during one-leg standing did not reveal a statistically significant difference among the three groups [F(2,33) = 825, P = 0.177]. (Refer to Figure 5C.) The analysis of anterior-posterior displacement during single-leg standing did not reveal a statistically significant distinction among the three groups [F(2,33) = 2.33, P = 0.113]. (Refer to Figure 5D).

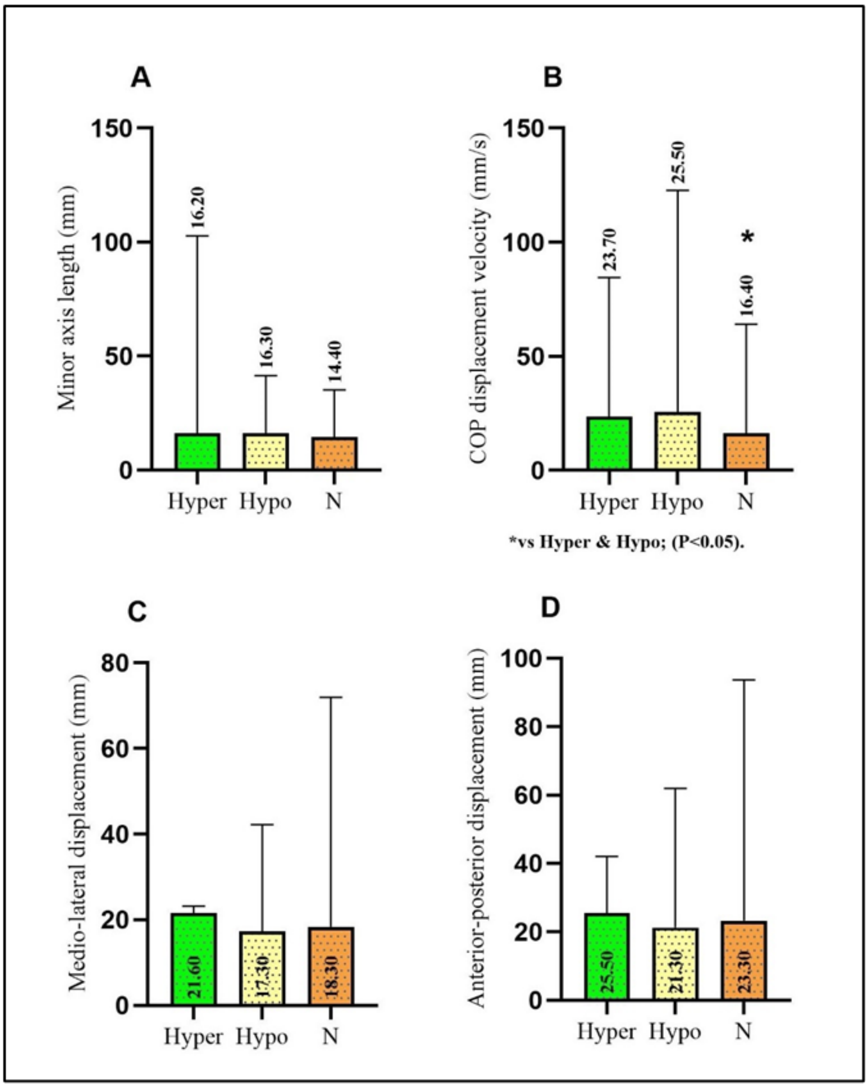

Figure 5. Results of One-Way ANOVA on the COP Sway Indices

Abbreviations: Hyperlordosis, Hyper; Hypolordosis, Hypo; Normal, N.

Differences in Anterior-Posterior Foot Pressure Symmetry during Single-Leg Stance among the Study Groups

The analysis of the symmetry of the front and back pressure of the foot in the single-leg standing posture revealed a notable disparity among the three groups [F(2,33) = 39.58, P = 0.001]. The pressure distribution between the front and rear legs differed considerably between the group with an excessive curvature of the lower spine (hyperlordosis) and the group with reduced curvature of the lower spine (hypolordosis). There was a notable distinction between the hyperlordosis and normal groups, as indicated by (P = 0.001 and 0.001).

Discussion

The study examined the postural control of athletes with and without persistent low back pain. The findings revealed a substantial difference between the three groups' minor axis, central axis, and swing range when standing on their legs. The hyperlordosis and hypolordosis groups had a considerably more extensive fluctuation range than the regular group. According to the 95% confidence ellipse indices, the group with normal lumbar lordosis had fewer postural variations. This suggests that keeping the lumbar spine in its normal alignment can prevent excessive bodily fluctuations.

Additionally, when standingon one leg, the study discovered no significant differences in the minor axis, but the hyperlordosis and normal groups showed substantial differences in the central axis. There was also a notable difference in the swing range between the hypolordosis and regular groups. Standing on one leg, the 95% confidence ellipse indices also demonstrated less postural variation in the group with normal lumbar lordosis.

Najafi et al. (2014) studied postural sway in athletes with non-specific persistent low back pain and good health. In both standing and closed-eye positions, they discovered a substantial difference in posture fluctuation between athletes with non-specific chronic low back pain and healthy athletes. Compared to healthy athletes, athletes with non-specific persistent low back pain had more significant postural fluctuation when standing with their eyes open and closed, suggesting that they may have a postural control issue (Najafi, 2019). Muller et al. (2015) concluded that non-specific persistent low back pain affects trunk motions and lower limbs. Hip rotation decreased when walking, chest rotation remained unchanged, and trunk rotation varied when running in individuals with non-specific chronic low back pain, suggesting that pain disrupts postural regulation (Muller, Blickhan, & Ertelt, 2015) Postural control in elite athletes with and without low back pain was studied by Oyarzo et al. (2014). The findings demonstrated that during posture control with eyes open, athletes experiencing back pain used more energy and moved their center of pressure, suggesting that back discomfort disrupts balance and raises the risk of injury (Oyarzo, 2014). The 95% certainty oval indicates that having good posture helps lessen postural fluctuations in back pain sufferers, which lowers their chance of injury and recurrence (Azadinia, 2020).

The study aimed to compare boys' static and dynamic posture control abilities with sagittal spine abnormalities. Following the preliminary screening process and measurement of 417 students' kyphosis and lordosis arches, 88 deformed individuals were randomly chosen and split equally into four groups: hyperkyphosis, hypokyphosis, hyperlordosis, and routine. The findings demonstrated that compared to the hypokyphosis and hyperlordosis groups, static and dynamic posture control were significantly poorer in the hyperkyphosis group. Furthermore, the hypokyphosis group had much better static and dynamic posture control than the hypolordosis group. The findings also demonstrated that the lumbar region's lordosis angle may impact specific markers associated with the center of pressure. The group exhibiting normal posture had lower displacement values than those with hyperlordosis and hypolordosis, suggesting greater stability in this group. Unfavorable posture hurts body balance management, according to research that has examined how posture affects body balance maintenance (Shoebridge, A, Shield, & Webster, 2020).

Posture can be affected by spinal column deformities that arise from acquired, hereditary, or unexplained causes (Saifee, 2024). According to a study by Nawrste et al. (2014), there are notable variations between individuals with lumbar hyperlordosis and those with normal lordosis regarding dynamic balance and central muscle endurance. The vertebrae's location and that of the agonist and antagonist muscles fluctuate about one another as the spinal arches rise and fall, and joint and muscle receptors malfunction in their ability to accurately send sensory data to the central nervous system (Nawrste, et al., 2014). People with atypical arches may also have diminished capacity to control posture due to muscle imbalance (Carrol, Paulseth, & Martin, 2022). The muscles are out of balance in the hyperlordosis and hypolordosis positions, which causes problems with muscular coordination when performing motor activities (Moustafa, 2021). People with hypolordosis may also have a reduction in shock absorption due to movement limitation of the vertebral column. This results in the spine not moving through its full range of motion, which increases the ground's response pressures on the body. This may lead to chronic back discomfort and instability in the entire body (Castillo & Lieberman, 2018).

In a study conducted in 2015, Darvish Safat et al. examined the ability of boys with sagittal spine anomalies to maintain control over their posture in static and dynamic situations. The findings indicated that the hyperkyphosis group had considerably worse static and dynamic posture control than the hyperkyphosis and hyperlordosis groups. In addition, the group with hyperkyphosis had much superior control over static and dynamic posture compared to the group with hyperlordosis. There was no discernible distinction between the groups exhibiting hyperlordosis and hypolordosis (Dervishsfat, 2019). The study concluded that the spine's posture influences the body's ability to control posture. One of the research's weaknesses was the absence of a healthy reference group with normal sagittal plane arches, which made it challenging to interpret the results (Dervishsfat, 2019).

Bruyneel et al. (2008) conducted a study to investigate the influence of scoliosis on the dynamic posture of 13-year-old females, comparing those with right-sided scoliosis to those without. According to the research, shifting the center of mass to the right causes a displacement of the center of pressure and disturbs balance. The study determined that the lordosis angle in the lumbar area affects postural stability (Bruyneel, 2008).

Based on the findings, there was no significant difference in the pressure symmetry between the left and right legs when standing on two legs across all three groups. When assuming a bipedal stance, a discernible discrepancy in the symmetry of the anterior and posterior pressure of the right leg was seen. The group with excessive lumbar lordosis experienced anterior foot pressure, while the group with less lumbar lordosis experienced posterior foot pressure. Individuals with decreased lumbar lordosis redistribute force and plantar pressure toward the posterior region of the foot, whereas individuals with increased lordosis redistribute it toward the anterior region of the foot (Kuo, 2020). Changes in weight distribution and pressure symmetry on the soles of the feet can lead to musculoskeletal ailments, including lower limb injuries, instability, and recurring back pain (Sivapuratharasu, Bull, & McGregor, 2019).

There is a lack of research on how the curvature of the lower back affects the pressure on the soles of the feet, and prior studies have not adequately investigated this pressure (Fernández-Seguín, 2014). Previous studies have confirmed that differences in the sagittal alignment of the spine can impact how the spine is loaded and subjected to external pressures (Weber, 2019). The curvatures of the spine, namely the lumbar arch, substantially impact maintaining an optimal standing posture and improving muscular efficiency (Chen, 2019). In hyperlordosis posture, the lumbar erector spinae and iliopsoas muscles are excessively active, while the gluteus maximus, hamstrings, and abdominal muscles are insufficiently engaged [36]. In cases of hypolordosis, there is an excessive contraction of the hamstrings, gluteus maximus, and lower abdominal muscles. In contrast, the contraction of the hip flexors and lumbar erector spinae is reduced (Ghorbani, 2021). This viewpoint implies that alterations to the curvature of the lower back also affect the muscles of the core and lower extremities (Dieën, 2019). Nevertheless, it remains uncertain whether the modification in the arch leads to pasteurization or a difference in muscle function [38]. Some experts suggest that poor back postures can signal changes in muscle activity and length-tension patterns, resulting in fatigue and reduced ability due to muscular imbalance (Dutta, 2020).

Implications

Maintaining proper lumbar alignment is crucial in enhancing postural stability and reducing asymmetry in plantar pressure, which is essential for preventing injuries, supporting effective rehabilitation, and optimizing athletic performance. These benefits highlight the significant implications of lumbar alignment for individual health and within the broader field of sports science.

Research Contributions

This research differentiates itself from previous studies examining lumbar alignment, plantar pressure, or postural sway by integrating all three factors into a unified framework. This comprehensive approach provides a more holistic understanding of the biomechanical processes underlying low back pain. Combining these elements, the study deepens our insight into the complex interactions contributing to the development and persistence of low back pain.

Limitations

This study has several limitations, including its cross-sectional design, which restricts the ability to establish causal relationships. Additionally, using a limited and homogenous sample, comprising only male athletes, may reduce the generalizability of the findings to broader populations. Furthermore, the reliance on two-dimensional postural evaluations presents a methodological constraint that may limit the precision and depth of biomechanical analysis.

Suggestions

Future research should adopt longitudinal designs to assess better causal relationships between lumbar alignment, plantar pressure, and postural control. Expanding the study population to include diverse groups such as women, older adults, and clinical cohorts would improve the generalizability of findings. Additionally, utilizing advanced biomechanical tools like three-dimensional motion analysis and electromyography would provide a more detailed and accurate evaluation of the underlying neuromuscular processes.

CONCLUSION

The study reveals that incorrect posture can disrupt posture control. Normal lordosis individuals show lower values in postural variability and pressure fluctuations, improving stability. Increased lordosis and back pain cause more significant pressure on the front of the feet, affecting the anterior regions of the lower limb. This results in increased pressure and weight support.

ACKNOWLEDGMENT

We extend our gratitude to all participants of this research for their collaboration throughout this academic endeavor.

AUTHOR CONTRIBUTION STATEMENT

D.L.S., H.A.M., H.A.R., and S.S.M., conceived and designed the experiments; D.L.S., and A.Y., performed the experiments; D.L.S., H.A.R., A.Y., S.S.M., H.A.M., contributed reagents/ materials/ analysis tools; D.L.S., data analysis; D.L.S., and H.A.R, writing original draft, review, and editing. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

REFERENCES

Alias, A.N., et al., Feet Plantar Pressure Distribution Among Female School Teachers. 2020. https://doi.org/10.21203/rs.3.rs-115018/v1

Azadinia, F., et al., The amount and temporal structure of center of pressure fluctuations during quiet standing in patients with chronic low back pain. Motor Control, 2020. 24(1): p. 91-112. https://doi.org/10.1123/mc.2018-0032

Bitenc-Jasiejko, A., K. Konior, and D. Lietz-Kijak, Meta-analysis of integrated therapeutic methods in noninvasive lower back pain therapy (LBP): The role of interdisciplinary functional diagnostics. Pain Research and Management, 2020. 2020. https://doi.org/10.1155/2020/3967414.

BRANTHWAITE, H., The impact of footwear choice on foot biomechanics in young adults with considerations to the potential risk of developing foot pathology. 2015, Staffordshire University.

Bruyneel, A.-V., et al., The influence of adolescent idiopathic scoliosis on the dynamic adaptive behaviour. Neuroscience letters, 2008. 447(2-3): p. 158-163. https://doi.org/10.1016/j.neulet.2008.10.007

Cani, P.D., et al., Akkermansia muciniphila: paradigm for next-generation beneficial microorganisms. Nature Reviews Gastroenterology & Hepatology, 2022. 19(10): p. 625-637. https://doi.org/10.1038/s41575-022-00631-9

Carroll, L.A., S. Paulseth, and R.L. Martin, Forefoot injuries in athletes: Integration of the movement system. International journal of sports physical therapy, 2022. 17(1): p. 81. https://doi.org/10.26603/001c.30021

Castillo, E.R. and D.E. Lieberman, Shock attenuation in the human lumbar spine during walking and running. Journal of Experimental Biology, 2018. 221(9): p. jeb177949. https://doi.org/10.1242/jeb.177949

Chamoli, U., Studies on lumbar spinal instability due to structural alterations and novel perspectives on spinal motion metrics. 2016, UNSW Sydney.

Chen, Y.-L., et al., Lumbar posture and individual flexibility influence back muscle flexion-relaxation phenomenon while sitting. International Journal of Industrial Ergonomics, 2019. 74: p. 102840. https://doi.org/10.1016/j.ergon.2019.102840

Dervishsfat, A.R., Sarshin, Comparison of static and dynamic posture control ability of boys with sagittal spine deformities. Scientific Journal of Kurdistan University of Medical Sciences 2016. 21(1): p. 47-59.

Dewar, R., S. Love, and L.M. Johnston, Exercise interventions improve postural control in children with cerebral palsy: a systematic review. Developmental Medicine & Child Neurology, 2015. 57(6): p. 504-520. https://doi.org/10.1111/dmcn.12660

Dutta, A., et al., Effects of working posture and roof slope on activation of lower limb muscles during shingle installation. Ergonomics, 2020. 63(9): p. 1182-1193. https://doi.org/10.1080/00140139.2020.1772378
Fernández-Seguín, L.M., et al., Comparison of plantar pressures and contact area between normal and cavus foot. Gait & posture, 2014. 39(2): p. 789-792. https://doi.org/10.1016/j.gaitpost.2013.10.018
Gallagher, K.M., The relationships of prolonged standing induced low back pain development with lumbopelvic posture and movement patterns. 2014.
Ghorbani, M., et al., The Effect of Three Methods of Kinesthetic Imagery, Active, and Combined Exercises on Electromyographic Pattern of Hip Hyperextension and the Muscle Strength of Gluteus Maximus and Abdominal in Women With Lumbar Hyperlordosis. Physical Treatments-Specific Physical Therapy Journal, 2021. 11(3): p. 145-156. https://doi.org/10.32598/ptj.11.3.36.3
Hmida, J., et al., Relationship between foot pressure and spinal parameters in healthy adults-A systematic review. Gait & posture, 2023. 103: p. 126-132. https://doi.org/10.1016/j.gaitpost.2023.05.006
Ivanenko, Y. and V.S. Gurfinkel, Human postural control. Frontiers in neuroscience, 2018. 12: p. 301583. https://doi.org/10.3389/fnins.2018.00171
Koch, C. and F. Hänsel, Non-specific low back pain and postural control during quiet standing-A systematic review. Frontiers in Psychology, 2019. 10: p. 438193. https://doi.org/10.3389/fpsyg.2019.00586
Kripa, S. and H. Kaur, Identifying relations between posture and pain in lower back pain patients: a narrative review. Bulletin of Faculty of Physical Therapy, 2021. 26: p. 1-4. https://doi.org/10.1186/s43161-021-00052-w\
Kuo, F.-C., D.-C. Cai, and B.-Y. Liau, Foot arch support effect on lumbo-pelvic kinematics and centre of pressure excursion during stand-to-sit transfer in different foot types. Journal of Medical and Biological Engineering, 2020. 40: p. 169-178. https://doi.org/10.1007/s40846-019-00499-2
Mizrahi, J.J.J.o.m. and b. engineering, Mechanical impedance and its relations to motor control, limb dynamics, and motion biomechanics. 2015. 35: p. 1-20. https://doi.org/10.1007/s40846-015-0016-9
Moustafa, I., et al., Demonstration of autonomic nervous function and cervical sensorimotor control after cervical lordosis rehabilitation: a randomized controlled trial. Journal of Athletic Training, 2021. 56(4): p. 427-436. https://doi.org/10.4085/1062-6050-0481.19
Müller, R., T. Ertelt, and R. Blickhan, Low back pain affects trunk as well as lower limb movements during walking and running. Journal of biomechanics, 2015. 48(6): p. 1009-1014. https://doi.org/10.1016/j.jbiomech.2015.01.042
Najafi Behzad, S.F., Minonezhad Hooman, Comparison of postural fluctuation in healthy and non-specific chronic back pain athletes. Bimonthly scientific-research journal of rehabilitation medicine, 2014. 3(3): p. 1-10.
Nawrste, A.a.D., Hassan; Waqefy, Jaefar; Shahhaidary, Sare, Comparison of strength, endurance and range of motion of the lumbar spine of athletes with and without back pain. 2014.
Ngiejungbwen, L.A., H. Hamdaoui, and M.-Y. Chen, Polymer optical fiber and fiber Bragg grating sensors for biomedical engineering Applications: A comprehensive review. Optics & Laser Technology, 2024. 170: p. 110187. https://doi.org/10.1016/j.optlastec.2023.110187
Oyarzo, C.A., et al., Postural control and low back pain in elite athletes comparison of static balance in elite athletes with and without low back pain. Journal of back and musculoskeletal rehabilitation, 2014. 27(2): p. 141-146. https://doi.org/10.3233/BMR-130427
Saifee, T., et al., Spinal Column and Spinal Cord Disorders. Neurology: A Queen Square Textbook, 2024: p. 463-498. https://doi.org/10.1002/9781119715672.ch14
Sainz de Baranda, P., et al., Sitting posture, sagittal spinal curvatures and back pain in 8 to 12-year-old children from the region of murcia (Spain): ISQUIOS programme. International journal of environmental research and public health, 2020. 17(7): p. 2578. https://doi.org/10.3390/ijerph17072578

Shah, A., et al., Spinal balance/alignment-clinical relevance and biomechanics. 2019. 141(7): p. 070805. https://doi.org/10.1115/1.4043650
Shah, A., et al., Spinal balance/alignment-clinical relevance and biomechanics. Journal of biomechanical engineering, 2019. 141(7): p. 070805. https://doi.org/10.1115/1.4043650
Shoebridge, A., N. Shields, and K.E. Webster, Minding the Body: An interdisciplinary theory of optimal posture for musicians. Psychology of music, 2017. 45(6): p. 821-838. https://doi.org/10.1177/0305735617691593
Sivapuratharasu, B., A.M. Bull, and A.H. McGregor, Understanding low back pain in traumatic lower limb amputees: a systematic review. Archives of Rehabilitation Research and Clinical Translation, 2019. 1(1-2): p. 100007. https://doi.org/10.1016/j.arrct.2019.100007
Smith, J.A., et al., Do people with low back pain walk differently? A systematic review and meta-analysis. Journal of Sport and Health Science, 2022. 11(4): p. 450-465. https://doi.org/10.1016/j.jshs.2022.02.001
Tanwar, P., et al., Various mechanisms of low back pain in the elderly population. 2022. 3(12): p. 55-61.
Urits, I., et al., Low back pain, a comprehensive review: pathophysiology, diagnosis, and treatment. Current pain and headache reports, 2019. 23: p. 1-10. https://doi.org/10.1007/s11916-019-0811-z
Van Dieën, J.H., et al., Motor control changes in low back pain: divergence in presentations and mechanisms. Journal of Orthopaedic & Sports Physical Therapy, 2019. 49(6): p. 370-379. https://doi.org/10.2519/jospt.2019.7917
Weber, C.I., et al., Effects of standing on lumbar spine alignment and intervertebral disc geometry in young, healthy individuals determined by positional magnetic resonance imaging. Clinical Biomechanics, 2019. 65: p. 128-134. https://doi.org/10.1016/j.clinbiomech.2019.04.010