Heliyon 10 (2024) e37379

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Postural and spinal stability analysis for different floor sitting styles

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ARTICLE INFO

Keywords:
Postural stability
Floor seating
Seating postures
Trunk muscle activity

ABSTRACT

In contrast to Western countries, traditional floor-seating cultures are prevalent in Korea, Japan, the Middle East, and Africa, where sitting on the floor in static positions such as squatting, kneeling, or sitting cross-legged is common. Most studies on sitting posture have predominantly focused on chair sitting in Western cultures, resulting in a cultural bias. This study aimed to investigate the effects of different cushion types (floor and traditional cushions of 3-cm, 5-cm, and 8-cm thickness) and seating postures (cross-legged, mother's leg, and kneeling) on measures of postural stability, trunk muscle activity, rotational spinal stability, and subjective postural stability in an Asian population. Forty right-hand and right-foot-dominant volunteers who did not experience activity-limiting back pain in the past 12 months were recruited. Multivariate analyses of variance (MANOVA) and ANOVA with a repeated-measures design were employed to assess the within-subject effects of the cushion type and seating posture. An alpha value of 0.05 was set for statistical significance. The results of this study suggest that preventing lordosis posture, seating on the floor, and maintaining a kneeling posture may reduce the loss of balance and trunk muscle fatigue. These results emphasize the need for additional ergonomic studies that focus on the seating traditions of Asian cultures.

1. Introduction

In contrast to Western countries, Korea, Japan, the Middle East, and Africa have traditional floor seating cultures [1]. Humans can assume more than 1000 positions [2] used for movements to maintain daily life activities. Culture significantly affects activities of daily living [3]. For example, the positions used for sitting often differ between West and East. In many regions, Asians do not use chairs, primarily at work or at home, because sitting without external support is still comfortable, in accordance with Oriental

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https://doi.org/10.1016/j.heliyon.2024.e37379
Received 29 March 2024; Received in revised form 2 September 2024; Accepted 2 September 2024
Available online 3 September 2024
2405-8440/

standards. Sitting on the floor in a static position, including squatting, kneeling, and sitting cross-legged, is more common [2,4–9]. To date, studies on sitting postures have focused on chair sitting posture and behavior in Western cultures and are culturally biased [4,5,10]. No studies have focused on substitution itself. This prejudice should be addressed because humans habitually crouch or squat at work or at rest [2,5].

The seating position on the floor varied regardless of the height and size of the floor varies [2,4,11,12]. This study focused on three sitting positions commonly used by Asian individuals to perform daily activities: squatting, kneeling, and sitting cross-legged. These positions are not limited to the East; they can be used by various populations and individuals, including those in Western societies. In Japan, kneeling is practiced during eating, socializing, and religious or traditional ceremonies [2,10,12–14]. Older women kneel to engage in social and religious activities [15]. In nontraditional Japanese families, people sit on the floor, and many restaurants have tatami rooms where people kneel to eat. In Islamic countries, kneeling is performed during religious practices. Those faithful to Islamic customs perform significant deep knee flexion throughout their lives [16]. For example, from the age of 7 years, Muslim individuals are required to kneel and pray in a mosque or home five times a day [3]. In Pakistan, people bend their knees approximately 70 times a day while praying. Rich people kneel more than poor people because they do not engage in manual labor or work in the field [17]. Hefzy et al. [18] examined the kinematics of knee flexion in the prayer posture in five healthy Saudi Arabian men using radiography [18]. They confirmed that the airway involved two main movements: (a) with the knees fully bent (150°–165°) and the torso upright, and (b) moving down from a kneeling position to a bending position (head touching the floor) with the flexion of the knee decreasing to 90° [16].

This cross-legged posture is called a tailored or Buddhist posture. This posture is used during relaxation, socializing, eating, working, leisure, and spiritual activities, such as yoga [16]. In Asia, many activities of daily living are performed while sitting cross-legged on the floor. Although this posture is mainly used in Asia and the Middle East [2,4,7–9,11,12,14,19–22], it is the least studied sitting position [16]. In Korea, the mother's leg is commonly used for daily activities, such as eating, tea, cookies, and the traditional deep bow (kowtow). Korea's traditional lifestyle refers to ondol under a floor heating system, which originates from floor-seating customs. In this sitting posture, the pelvis is rotated in a more dorsal direction, and the lumbar lordosis is flattened more during this posture than while sitting on a chair. Cross-legged sitting exerts a significant load on the intervertebral discs and spine, especially in a slumped position, which increases disc pressure and aggravates chronic low back pain [23]. The use of cushions is a crucial culture for floor seating. A cushion usually reduces the interface pressure between the human body and the floor, providing comfort to users. Using a cushion in floor seating is essential for enhancing comfort by reducing interface pressure and evenly distributing body weight, which helps prevent discomfort or pain [24,25]. Recent studies have emphasized that the hardness and thickness of a cushion, as measured by its indentation force deflection or indentation load deflection, are critical to the user's spine and pelvis. The hardness of a cushion affects spinal alignment; cushions that are too hard can lead to poor posture and spinal strain, while cushions that are too soft can cause pelvic tilt and improper spinal curvature. Proper cushion thickness is also crucial; too thin, padding, or too thick can cause instability and misalignment of the pelvis and spine. Therefore, in floor seating, appropriate cushion properties are essential [26,27].

One study examined spinal stability by using electromyography (EMG) in a laboratory environment. Changes in the sitting position have been reported to cause more changes in the imaging EMG for the triceps brachii, pectoralis major, and deltoid muscles [28]. Chris et al. [29] evaluated the spinal EMG response in three unsupported postures following whole-body vibration: neutral upright, forward lean, and posterior lean postures. The magnitude of the vibrational synchronous response of the erector spinae (ES) musculature varies according to body posture [29]. Using analysis of variance (ANOVA), Soderberg et al. [30] determined the significant differences between postures. EMG activity decreased with an increase in chair seat tilt [30]. Although several studies have been conducted on sitting postures, studies specifically focusing on postures in Asian individuals are lacking.

The effects of the seating posture and cushion use on lordosis, kyphosis, and free spinal curvature were examined. It was hypothesized that the type of cushion significantly influences postural stability and increases trunk rotational stiffness through enhanced coactivation of trunk muscles. Additionally, it was hypothesized that different postures would significantly affect postural stability and increase trunk rotational stiffness by increasing trunk muscle coactivation. This study investigated the impact of cushion type (floor, 3 cm, 5 cm, 8 cm, and traditional cushions) and posture type (binary legs, mother's legs, and knees) on postural stability, muscle activity, rotational spinal stability, and perceived difficulty in maintaining posture. The hypotheses were tested using multivariate analysis of variance (MANOVA) and ANOVA, employing a repeated-measures design to analyze the within-subject effects of cushion and posture types. Statistical significance was set at an alpha level of 0.05.

2. Materials and methods

2.1. Ethical statement

This study and all experimental protocols were approved by the Institutional Review Board of the Korea Research Institute of Standards and Science (KRISS), and all experimental protocols were approved for IRB research by KRISS (KRISS-IRB-2017-08).

2.2. Experimental design

In this study, 40 volunteers who were right- and right-foot-dominant were recruited because the dominant hand should be considered when examining lumbar muscle responses [31] and had not experienced back pain in the past 12 months that restricted their activities. Additionally, the experiment was conducted with only male participants to control for gender effects. The average (standard deviation) age, height, weight, and body mass index of the participants were 25.6 ± 4 years, 171.6 ± 5.7 cm, 67.4 ± 9.6 kg, and 22.9 ± 2.8, respectively. Table 1 presents the participants' demographic characteristics. The age group selected for Table 1, with a coefficient of variation of 15 %, was chosen based on the aim of recruiting participants with a spine as normal as possible for the experiment. It is widely recognized that spinal curvature tends to increase with age [32]. Therefore, focusing on a younger group, specifically individuals in their 20s, helped ensure a more consistent baseline spinal condition among participants.

Participants who met the study inclusion criteria received information regarding the purpose and methods of the study and signed a consent form approved by the institutional review board. All the participants agreed to participate in the study and were allowed to post identification images in online open-access publications. Relevant guidelines and regulations were adhered to in all methods. To assess seated postural stability, the distance of the center of pressure (COP) in the anterior/posterior (A/P) and left/right (L/R) directions beneath the buttocks was quantified by measuring the pressure on a pad (190 × 80 cm) using 32 × 32 digital film sensors developed by VISTA and Medical Company with an FSA Pressure Mapping System (Fig. 1). An eight-channel EMG system, ME-6000T (Mega Win, Kupio, Finland) was used to monitor the EMG activity of the eight trunk muscles and estimate their overall contribution to the rotational stiffness of the spine in each of the following cardinal planes: sagittal, coronal, and transverse at L4/L5. Rotational spine stiffness was computed using the activity of the eight trunk muscles as a measure of spinal or trunk muscle activation (Fig. 1). This computation was based on a previous study [33]. Spinal stability is reportedly associated with trunk muscular stiffness [33] based on the association between muscle force and muscle stiffness [34]. All experiments were performed using a 6-mm digital camcorder.

In this experiment, a 3 × 3 × 5 within-factor design was used to examine the effect of cushion and seating postures on biomechanical measures of normalized muscle activity (Fig. 2) and subjective and objective seated postural and spinal stability.

The independent variables for the experiment included the type of cushion (five levels: floor, traditional cushion, and memory foams with thicknesses of 3-, 5-, and 8-cm thickness), type of seating posture (three levels: kneeling, sitting cross-legged, and mother's leg), and type of spinal posture (three levels: free, kyphotic, and lordotic), which are within-subjects factors. In this study, the dependent variables encompassed both directly measured outcomes and derived metrics. The directly measured dependent variables included objective measures of seated postural stability, specifically the location of the Center of Pressure (COP) in the anterior-posterior (A/P) and left-right (L/R) directions, as well as the normalized muscle activity of the eight trunk muscles using EMG. Additionally, we analyzed and interpreted several derived variables such as 'seated postural stability, rotational spinal seated stiffness variables,' and 'subjective difficulty in maintaining postural stability. These derived variables were the outcomes of our analytical processes applied to direct measurements. These findings contribute to our understanding of the broader relationships and implications between the factors investigated and physiological responses measured in our study. Before beginning the experiment, the study objectives and procedures were explained to participants. To evaluate spinal stability, EMG electrodes were bilaterally attached to the following muscles related to spinal stability: rectus abdominis (RA), external oblique (EO), latissimus dorsi (LD), and ES [35,36]. To normalize the EMG signals, we used a fixture that could stabilize the lower body to accommodate the trunk isometric maximum voluntary contraction (MVC) in different directions to enable maximum muscle activation of the eight trunk muscles [36]. The EMG signals were sampled at 1000 Hz, and a bandpass filter was used to obtain signals between 20 and 500 Hz. The EMG was processed and normalized using an EMG-driven model with maximum values [36], which were then incorporated into the model developed by Rashedi et al. [33] to estimate the stiffness of the muscle and the total muscular contribution to the rotational stiffness of the spine at L4/L5, as detailed in the next section [33].

Following measurement of the participants' MVC, we asked them to wear loose cotton shorts that did not press their bodies. Each participant performed 45 experiments, with three types of posture and three types of spinal curvature on five types of cushions. A pressure mat was placed on the cushion to measure the stress exerted on the participants. Each experiment was conducted for 10 min (Fig. 3).

A 5-min break was provided between each experimental condition to prevent experimental fatigue, and a Latin square design was used to reduce carryover effects. Seated postural stability was evaluated for 1 min by using a pad (190 × 80 cm) equipped with 32 × 32 digital film sensors. When the task was completed, the participants assessed the subjective difficulty in maintaining a seated posture using the 10-point Borg scale [37].

2.3. Postural stability calculation

To measure the location of the COP, the coordinates of the cells in the pressure mat that detected the pressure exerted by contact with the body were identified. The coordinate value of the boundary of the detected cells was calculated as the distance between the line LR with L COP and R COP (L/R) and AP with A COP and P COP (A/P; Fig. 4).

The COP was calculated as Equation (1):

Table 1
Mean participant demographics.

	Age (Year)	Height (cm)	Weight (kg)	BMI (kg/m^2)
Average	25.6	171.6	67.4	22.9
SD	4.0	5.7	9.6	2.8
Max	34	178	86.0	27.1
Min	22	164	58.0	18.7

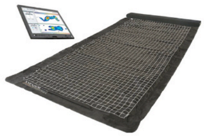
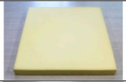
Specification	Picture
Pressure Mat	
-Made by VISTA Medical Company -Size: 190 cm length x 80cm width -Sensors: 1024 (32 x 32) -Sensor coverage: 62.5mm*31.25mm : Maximum pressure: 100mmHg(1.93PSI) -FSA Pressure Mapping System	
EMG (Electromyography)	
-Made by Kupio, Finland : ME 6000T : 8channels.	
Foams	
-Memory foam * -Size: 51 x 51 x 3 cm	
-Memory foam -Size: 51 x 51 x 5 cm	
-Memory foam -Size: 51 x 51 x 8cm	
-Korea Traditional cushions -Ramie cloth + cotton -Size: 51 x 51 x 3cm (center)	

Fig. 1. Experimental Equipment × Foams (Density: 33.5 kg/m^2, Hardness: 7.2 kg/314 cm^2, Tear strength: 0.6 kg/m^2, Tensile strength: 1.0 kg/cm^2, Elongation: 110 %, Rebound: 5 %), Test method (KSM 6672, JIS 6401).

$$COP\ \overline{x} = \frac{\sum_{i=1}^{n}\left(\sum_{j=1}^{n} P_{ij} \times a \times i\right)}{\sum_{j=1}^{n}\sum_{i=1}^{n} P_{ij}}, COP\ \overline{y} = \frac{\sum_{j=1}^{n}\left(\sum_{i=1}^{n} P_{ij} \times b \times j\right)}{\sum_{j=1}^{n}\sum_{i=1}^{n} P_{ij}} \tag{1}$$

a = length of one cell of the pressure mat; 62.5 mm.

b = width of one cell of the pressure mat; 31.25 mm

n = number of cells in the pressure mat; 32.

Normalization of the reference point was calculated as Equation (2):

$$L-R = \min\left(\frac{\overline{\text{L COP x}}}{\overline{\text{LR}}}, \frac{\overline{\text{R COP x}}}{\overline{\text{LR}}}\right), A-P = \min\left(\frac{\overline{\text{A COP y}}}{\overline{\text{AP}}}, \frac{\overline{\text{P COP y}}}{\overline{\text{AP}}}\right) \tag{2}$$

2.4. Spinal stability calculation

To calculate spinal stability, normalized EMG signals from each muscle were used to determine their contribution to the rotational muscular spinal stiffness K_j, which was calculated using the following Equation (3) [33]:

$$K_j = \sum_{i=1}^{8} d_{ij}^2 k_i \tag{3}$$

where the ith-muscle stiffness is k_i, and its moment arm in the jth plane is d_{ij}. Muscle stiffness and force were calculated as previously described as Equation (4) [34,36]:

$$k_i = q\frac{F_i}{l_i} and F_i = G \cdot PCSA_i \cdot NEMG_i \tag{4}$$

where q is the proportionality constant; G is the maximum allowable muscle stress; and $NEMG_i$, $PCSA_i$, and l_i are the normalized EMG, physiological cross-sectional area, and length of the ith muscle, respectively. Upon collecting these terms, K_j can be expressed as Equation 5

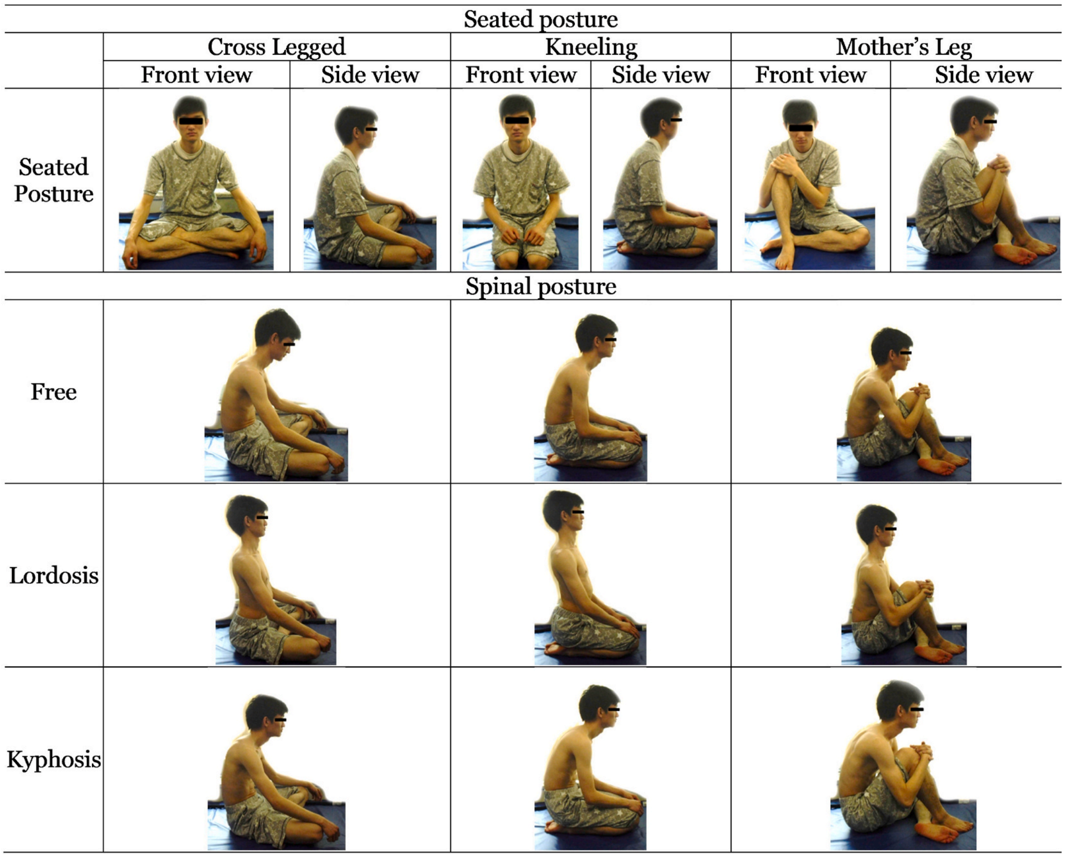


Fig. 2. Definition of the seating and spinal postures.

Fig. 3. Experimental scene.

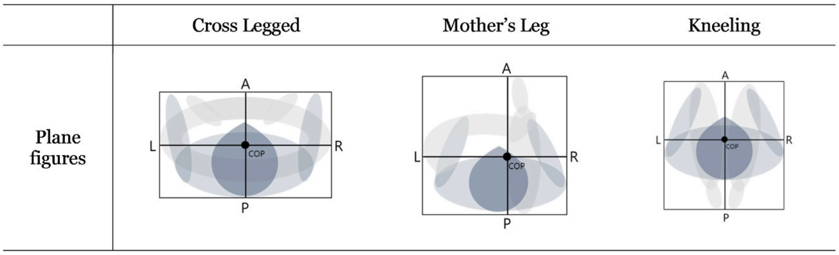


Fig. 4. Definition and calculation of COP with L-R and A-P.

$$K_j = q \cdot G \sum_{i=1}^{8} \frac{PCSA_i}{l_i} \cdot NEMG_i \cdot d_{ij}^2 \tag{5}$$

Because we did not estimate q and G without loss of generality, we calculated the scaled muscular spine rotational stiffness in each cardinal plane $\widetilde{K}_j$, as Equation (6):

$$\widetilde{K}_j = \frac{K_j}{q \cdot G} = \sum_{i=1}^{8} \frac{PCSA_i}{l_i} \cdot NEMG_i \cdot \tag{6}$$

Table 2
F-value (EMS) of ANOVA for Seated Postural and Spinal Stability Measures (The EMS shown in the interaction for the entire factor is the EMS value of the residual.).

	cushion	seated posture	spinal posture	cushion × seated posture	cushion × spinal posture	seated posture × spinal posture	cushion × seated posture × spinal posture
ANOVA for the COP distance							
Left/Right	1.944 (0.009)	1.337 (0.006)	0.656 (0.006)	1.126 (0.003)	0.543 (0.001)	0.463 (0.007)	0.531 (0.005)
Anterior/Posterior	0.634 (0.003)	25.511[b] (0.065)	1.503 (0.006)	1.240 (0.003)	0.421 (0.001)	2.903[a] (0.005)	1.024 (0.003)
Subjective difficulty in postural stability (ANOVA)							
Subjective discomfort	11.071[b] (9.997)	29.939[b] (21.508)	11.591[b] (19.409)	1.227 (5.171)	1.493 (4.566)	2.803[a] (6.336)	1.083 (4.986)
Muscle Activity							
ANOVA for individual muscles							
(L) Rectus Abdominis	1.688 (5.192)	1.007 (5.319)	3.645[a] (9.664)	1.628 (4.469)	1.705 (5.350)	1.450 (4.868)	1.276 (4.039)
(R) Rectus Abdominis	0.295 (4.795)	0.518 (4.668)	3.875[a] (10.604)	1.302 (3.542)	1.704 (5.455)	1.546 (5.158)	1.122 (4.430)
(L) External Obliquus	1.320 (2.968)	1.930 (5.542)	1.594 (4.885)	1.368 (4.962)	0.536 (2.472)	0.997 (2.036)	1.282 (3.244)
(R) External Obliquus	0.798 (3.033)	2.377 (5.564)	3.581[a] (8.905)	1.095 (4.019)	0.986 (2.184)	0.292 (1.172)	1.366 (3.027)
(L) Latissimus Dorsi	1.678 (4.934)	2.184 (7.463)	5.770[a] (23.719)	0.227 (2.005)	1.252 (2.928)	1.265 (3.175)	1.483 (2.662)
(R) Latissimus Dorsi	0.190 (3.335)	0.287 (3.846)	5.229[a] (23.973)	0.836 (3.738)	0.573 (2.465)	0.850 (4.887)	0.865 (3.408)
(L) Erector Spinae	2.778[a] (6.236)	8.119[b] (16.372)	11.113[b] (19.286)	1.604 (5.053)	0.459 (3.991)	1.721 (6.188)	0.734 (4.782)
(R) Erector Spinae	2.791[a] (6.821)	4.415[a] (12.677)	6.275[b] (16.206)	0.992 (3.590)	0.631 (2.793)	0.868 (3.825)	1.104 (3.462)
Spinal Stability (stiffness)							
ANOVA for all stiffness values							
Sagittal plane	3.506[a] (5.027)	4.977[a] (6.576)	9.991[b] (11.062)	1.267 (3.729)	0.492 (1.991)	1.194 (4.643)	1.074 (3.268)
Coronal plane	1.449 (3.869)	2.352 (4.359)	11.107[b] (13.318)	0.375 (3.652)	0.537 (3.872)	1.122 (3.778)	1.252 (3.053)
Transverse plane	3.388[a] (6.394)	5.097[a] (8.853)	9.370[b] (10.207)	1.348 (3.819)	0.512 (3.178)	1.185 (3.881)	1.012 (3.577)

[a] : $p < 0.05$.
[b] : $p < 0.01$.

2.5. Analysis

ANOVA was used with a repeated-measures design to investigate the main and interaction effects of the independent variables (type of cushion, seated posture, and spinal posture) on each dependent variable (objective and subjective measures of seated postural stability and spinal stability). Multiple comparisons of means were performed using post-hoc analysis. The Bonferroni correction was applied. All statistical analyses were performed using SPSS version 18 (IBM Corp., Armonk, NY, USA).

3. Results

The F-values and EMS of the ANOVA for all seated postural and spinal stability measures used to assess the main and interaction effects of the cushion, posture, and curvature are reported in Table 2.

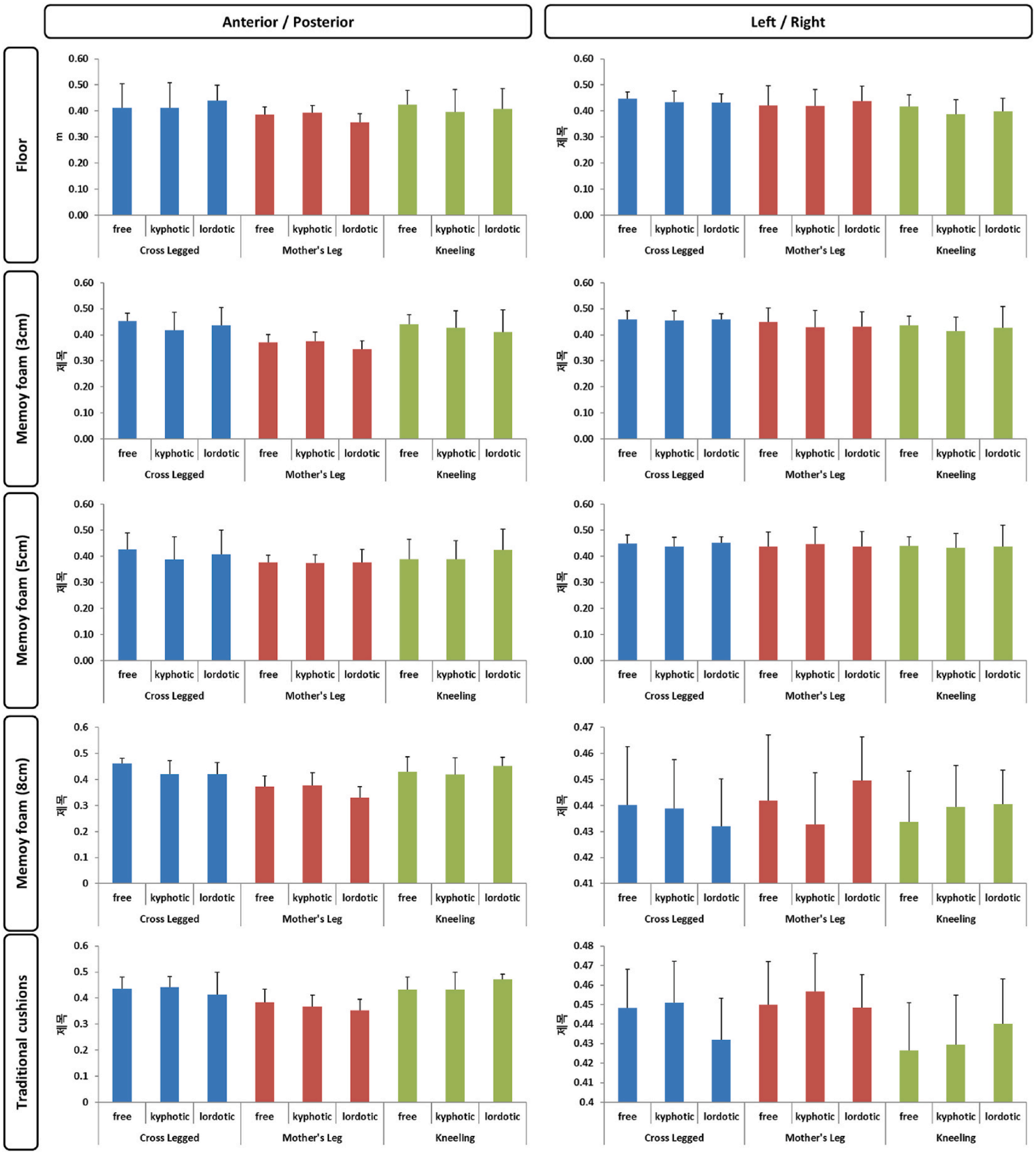


Fig. 5. Descriptive statistics of the measures of center of pressure; distance for the seated posture depending on the type of cushion, seated posture, and spinal posture.

3.1. Postural stability

The ANOVA results revealed a significant difference in the AP COP distance owing to the main effect of seated posture ($p < 0.01$), seated posture, and spinal posture two-way interaction effects ($p < 0.05$; Table 2). Descriptive statistics of the seated postural stability measures are shown in Fig. 5.

The A/P COP distance was significantly larger for the cross-legged and kneeling postures regardless of the curvature (Fig. 6).

3.2. Subjective difficulty maintaining postural stability

Fig. 7 presents the participants' responses to the Borg scale regarding their subjective difficulty maintaining their posture under different conditions. The ANOVA results indicated a significant difference in subjective difficulty due to the main effects of the cushion ($p < 0.01$), seated posture ($p < 0.01$), spinal posture ($p < 0.01$), and seated posture and spinal posture two-way interaction effects ($p < 0.05$; Table 2). The subjective difficulty in maintaining postural stability was significantly greater for floor sitting with the cushion (Fig. 7a). Moreover, the subjective difficulty in maintaining postural stability was significantly higher for kyphosis, regardless of posture (Fig. 7b).

3.3. Spinal stability

The normalized trunk muscle activity is shown in Fig. 8. During kyphosis, high muscle activity is observed in the left and right rectus abdominis. The right external oblique, left and right latissimus dorsi, and ES muscles are activated during lordosis. During kneeling, increased activity was observed in the left and right ES muscles. Moreover, increased muscle activity was observed on the left and right floors and the left and right ES muscles (Fig. 8).

The ANOVA findings of muscle activity are presented elsewhere, and we report only the significant overall effects of these altered coactivation patterns on rotational spine stiffness (Fig. 9).

The ANOVA results indicated an increased sagittal stiffness for lordosis, floor, and kneeling in the spinal, cushion, and seated postures (Fig. 10a, Table 2). Lordosis of the spinal posture significantly increased coronal spine stiffness (Fig. 10b–Table 2). Lordosis of the spinal posture, cushion floor, and seated posture significantly increased the transverse stiffness (Fig. 10c–Table 2).

4. Discussion

In this study, we examined postural stability, spinal stability, and subjective difficulty in maintaining postural balance under different types of cushions, seated postures, and spinal postures.

These results indicate that the margin of stability was decreased by lordosis in the mother's leg. The reduced margin of stability in lordosis led to a shift in the COP to the back of the body. Subjective discomfort increased with lordosis. Moreover, the lordotic posture tended to increase the force required to raise the spine with sagittal and coronal stiffness. The results demonstrated the possibility of maintaining lordosis posture-related disorders such as musculoskeletal and back pain.

The margin of stability did not affect the COP in terms of cushion type. Subjective discomfort decreased in the 3-cm and traditional cushions. In the case of floor seating, the increased COP induced discomfort. Moreover, the use of 5 8-cm cushions reduces body stability owing to the high thickness and softness. Although no significant difference was observed, the sagittal and transverse stiffnesses increased with cushion thickness. The softness of the cushion makes it challenging to maintain balance. These results suggest the importance of appropriate softness and thickness of the cushion because using a cushion with more than a 5-cm cushion increased

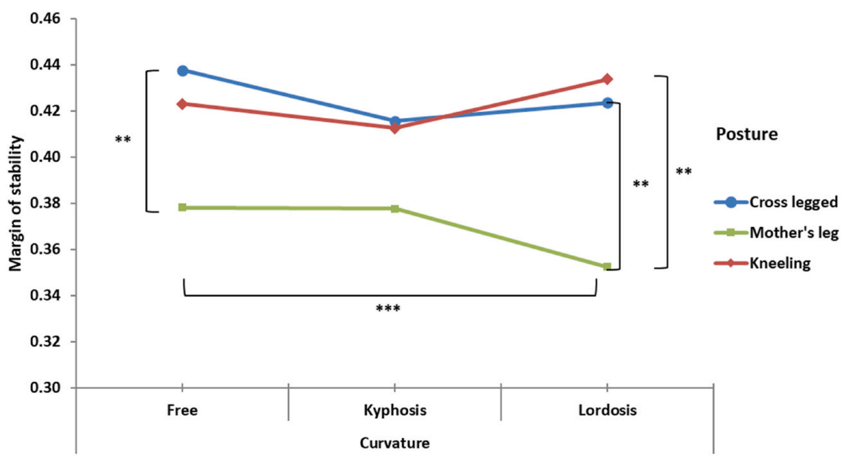


Fig. 6. Interaction effect of curvature and posture on the anterior and posterior (**: $p < 0.05$, ***: $p < 0.01$).

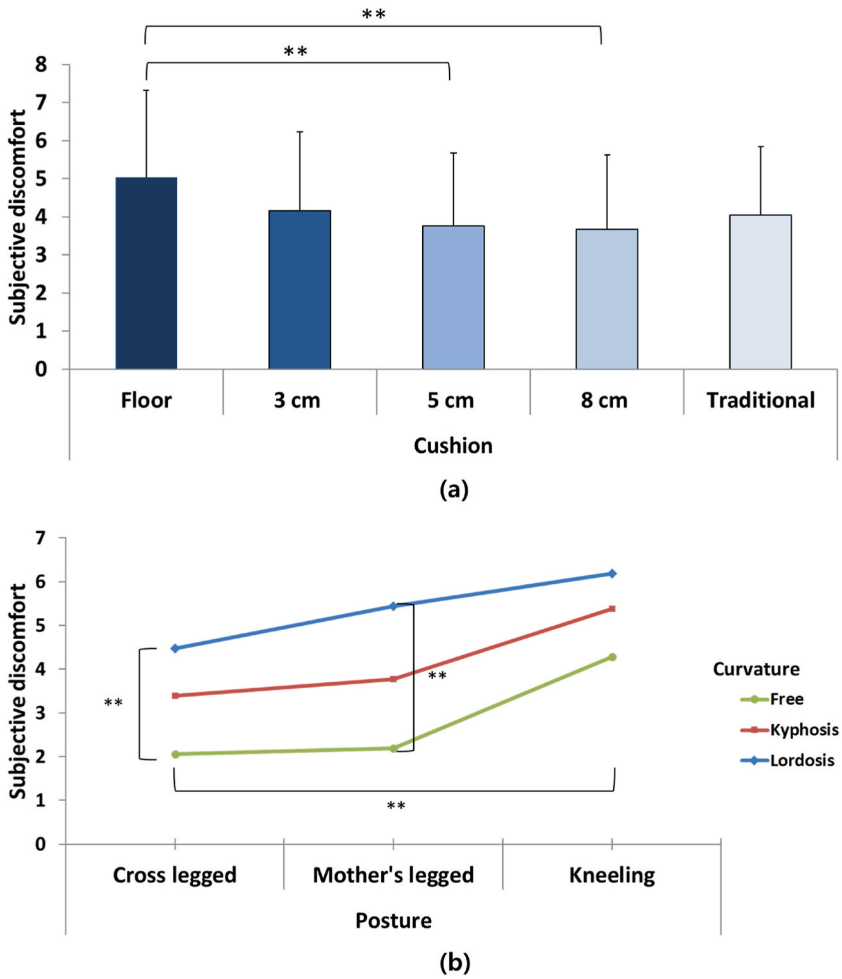


Fig. 7. Main effect cushion (a) and interaction effect of posture and curvature (b) on subjective discomfort (**: $p < 0.05$, ***: $p < 0.01$).

subjective discomfort and spinal stiffness.

The margin of stability decreased with the mother's legged position in the seated posture. This posture involves holding only one side of the leg and maintaining the posture with decreased hip stability. Subjective discomfort in the kneeling posture increased with sagittal and transverse stiffness. These results revealed that, unlike other postures using the buttock muscles, the kneeling posture using the tibialis increased subjective discomfort. Sagittal stiffness increases because more effort is required to assume the lordosis posture during kneeling than in other postures. These results indicate the possibility of maintaining lordosis in kneeling posture-related musculoskeletal and back pain disorders.

This result indicates that an appropriate seated posture for Asians does not cause musculoskeletal disorders or back pain.

The absence of female participants limits the generalizability of our findings across sexes. Including female participants may have enriched the analysis and provided a more comprehensive understanding of the study topic. Therefore, this limitation should be considered when interpreting the results, and future research should aim to include both male and female participants to enhance the overall understanding. Another limitation of this study is that it did not assess the prolonged effects of floor-sitting style. Specifically, the study did not investigate how extended periods of sitting in these styles might affect outcomes such as subjective discomfort. Therefore, it is essential to acknowledge that different outcomes could potentially arise from longer sitting durations in these positions when interpreting the findings.

5. Conclusions

This study investigated the effects of various cushions, seated postures, and spinal postures on postural stability and subjective difficulty in maintaining postural balance. Our results demonstrate that lordosis, especially in the mother's leg posture, significantly reduced the margin of stability and shifted the center of pressure (COP) towards the back, increasing subjective discomfort and the effort required to elevate the spine. This suggests the potential of lordosis-associated musculoskeletal and back pain disorders. The type of cushion did not significantly influence the COP; however, using cushions thicker than 5 cm increased subjective discomfort and

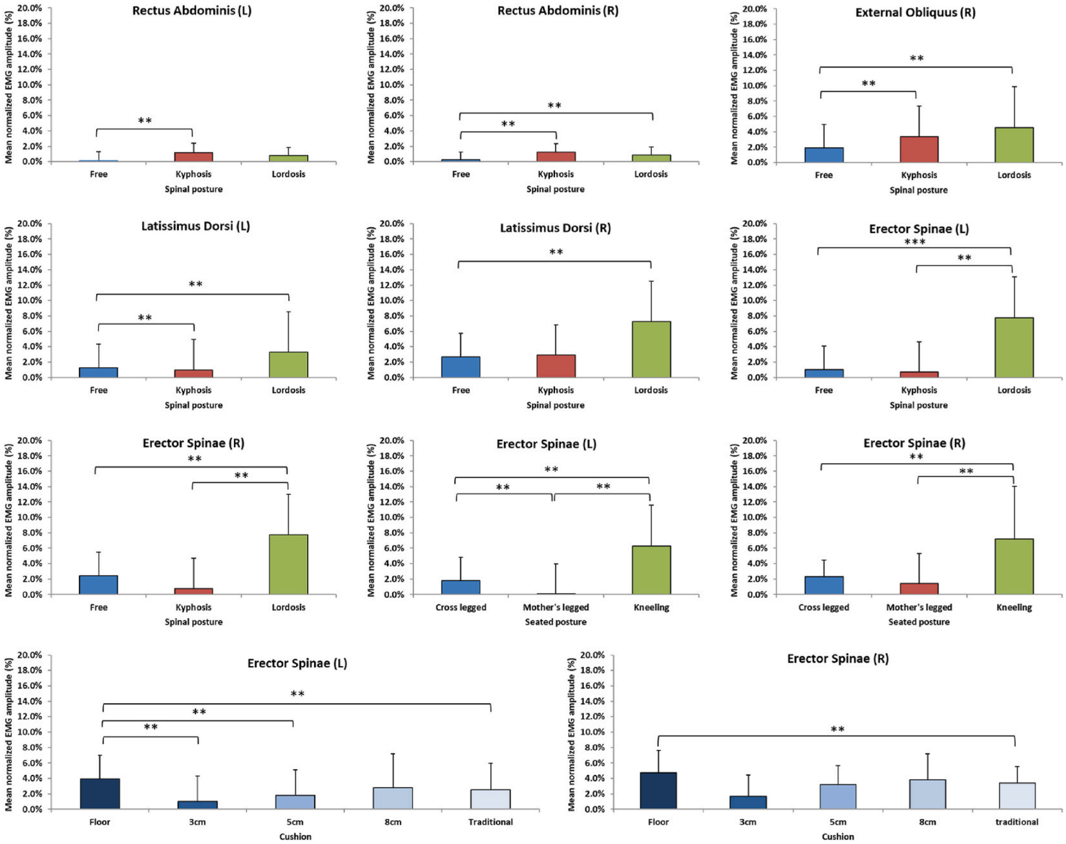


Fig. 8. Significantly different normalized EMG of cushion, seated posture, and spinal posture (**: p < 0.05, ***: p < 0.01).

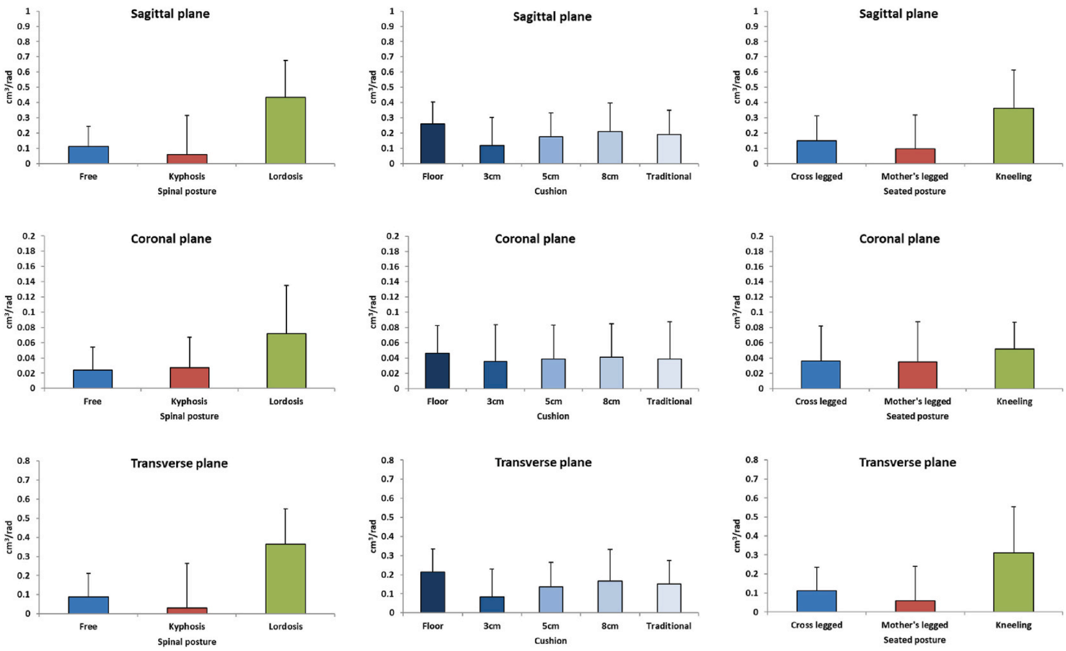


Fig. 9. Descriptive statistics for the measures of stiffness: sagittal, coronal, and transverse.

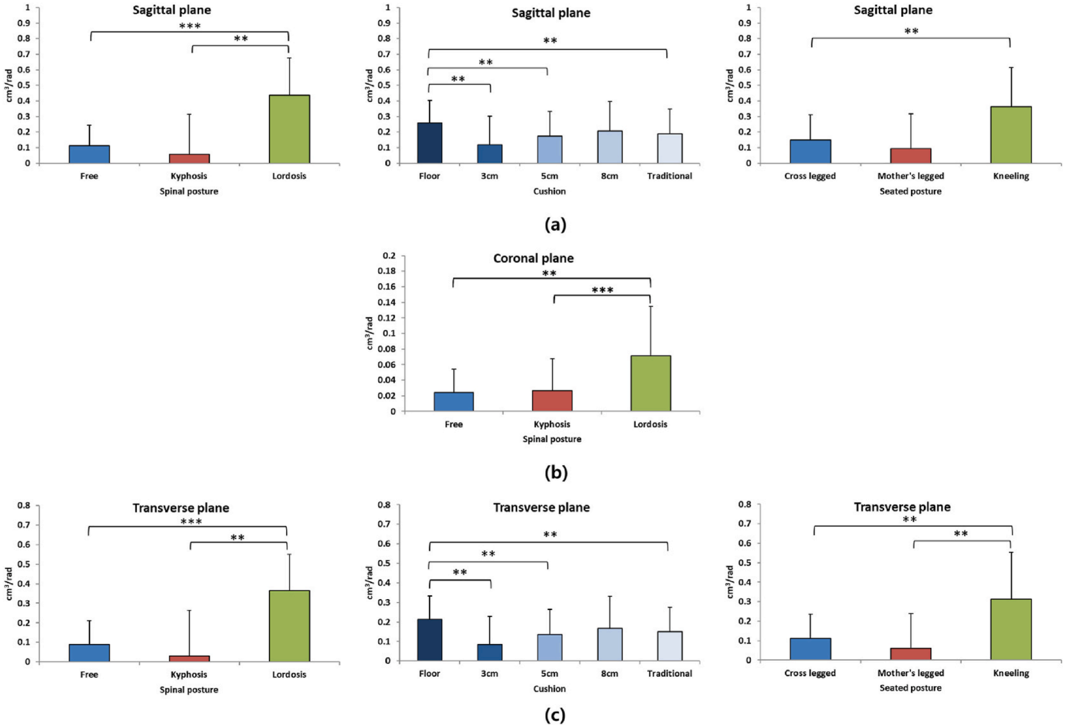


Fig. 10. Main effects of spinal posture, cushion, and seated posture on rotational spinal (a) sagittal stiffness, (b) coronal stiffness, and (c) transverse stiffness (**: $p < 0.05$, ***: $p < 0.01$).

spinal stiffness, highlighting the importance of the softness and thickness of the right cushion for optimal support. In conclusion, an appropriate seated posture in Asians does not cause musculoskeletal disorders or back pain.

Funding statement

This work was supported by Korea Gas Corporation, South Korea (2023–0054).

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Seung Nam Min: Project administration, Methodology, Formal analysis, Conceptualization. **Murali Subramaniyam:** Writing – review & editing. **Mohammad Parnianpour:** Writing – review & editing. **Dong Joon Kim:** Writing – review & editing, Methodology, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

We would like to thank Editage (www.editage.co.kr) for English language editing.

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