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Exploring the dynamics of stability and lumbar proprioception in hypermobility syndrome: a comparative and mediation analysis

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Abstract

Background HMS is characterized by excessive joint mobility, presenting various physical and psychological challenges. Understanding the interplay between these factors is essential for effective HMS management. This study aimed to examine differences in Limits of Stability (LOS) and lumbar proprioception between Hypermobility Syndrome (HMS) and control groups, explore correlations between LOS and proprioception errors, and understand the mediation effects of Kinesiophobia and fatigue on proprioception in HMS individuals.

Methods In this cross-sectional study, 72 HMS patients and 72 control participants were assessed. LOS was evaluated using a computerized Iso-free stabilometric force platform, lumbar proprioception was measured with digital inclinometers, and Kinesiophobia was quantified using the Tampa Scale of Kinesiophobia (TSK). Fatigue was assessed through standardized fatigue scales. Pearson correlation and mediation analyses were employed for statistical examination.

Results Individuals with HMS showed significantly lower LOS (mean differences ranging from 7.79 to 37.69%) and higher lumbar proprioception errors (mean differences from −1.09° to -2.88°) compared to the control group. Moderate negative correlations between LOS and proprioception errors were observed (r values from −0.45 to -0.60). Mediation analysis revealed significant roles of Kinesiophobia (indirect coefficient = -0.14, $p = 0.049$) and fatigue (indirect coefficient = -0.135, $p = 0.047$) in the relationship between LOS and proprioception.

Conclusion This study highlights significant balance and proprioception deficits in HMS individuals, with substantial mediation effects of psychological and physical factors. These findings emphasize the need for an integrated approach in HMS management, combining physical therapy with psychological interventions.

Keywords Hypermobility syndrome, Limits of stability, Lumbar proprioception, Kinesiophobia, Fatigue, Mediation analysis

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Background

Hypermobility Syndrome (HMS) is a connective tissue disorder characterized by excessive joint mobility, frequently leading to musculoskeletal complaints such as joint pain, instability, and an increased risk of dislocations and injuries [1]. While joint hypermobility is prevalent in the general population, HMS is differentiated by its clinical manifestations, which can significantly impact daily activities and overall quality of life [2]. Individuals with HMS often experience chronic pain, fatigue, and psychological distress, which further exacerbate their functional limitations [2].

Postural control and balance are critical components of functional mobility, and deficits in these areas are commonly observed in individuals with HMS [3]. Limits of Stability (LOS), a key biomechanical parameter, quantifies the maximum displacement of the center of gravity without losing balance [4]. Due to increased joint laxity and impaired neuromuscular control, individuals with HMS exhibit reduced LOS, which predisposes them to falls and instability [5]. In addition to balance impairments, proprioceptive deficits, particularly in the lumbar region, are prevalent in HMS [6]. Lumbar proprioception, which involves the accurate perception and control of spinal movement and position, is essential for maintaining postural alignment and preventing excessive joint strain [7]. Altered proprioception in HMS may contribute to poor movement patterns and increased injury risk [8].

Beyond the mechanical and neuromuscular impairments, psychological factors such as Kinesiophobia (fear of movement) and physical conditions like fatigue may influence proprioceptive function in HMS [9]. Kinesiophobia can lead to activity avoidance, further weakening neuromuscular responses, while fatigue may diminish proprioceptive acuity and postural control [10]. However, the interplay between these factors remains underexplored. This study aims to investigate differences in LOS and lumbar proprioception between HMS and control groups, examine their correlation, and assess the mediating effects of Kinesiophobia and fatigue on proprioception. Understanding these relationships will provide insights into HMS management strategies, emphasizing the need for multidisciplinary interventions that address physical and psychological factors.

Materials and methods

Study design, ethics, settings, and duration

This cross-sectional study was designed to explore the relationships between HMS, LOS, lumbar proprioception, and the mediating roles of kinesiophobia and fatigue. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of KKU (ECM# 2021–4404). Prior to participation, all subjects provided written informed consent after being fully briefed about the study's purpose, procedures, potential risks, and benefits. The study was carried out at the research lab of physical therapy, DMRS, CAMS, King Khalid University, a specialized center with the necessary equipment and expertise for conducting detailed assessments of balance, proprioception, and psychological factors. The study spanned 12 months, commencing in November 2021 and concluding at the end of March 2022.

Sample size calculation

The sample size for our study was determined using G*Power statistics with an anticipated effect size (Cohen's d) of 0.46, which is considered a medium effect size. We set our alpha at 0.05 and aimed for a power of 0.80, the standard value for clinical research, to detect significant differences in proprioception [11]. Based on these parameters, G*Power indicated a required sample size of 64 participants per group. To account for an estimated dropout rate of 10%, we decided to recruit 72 participants per group, resulting in a total of 144 participants.

Participants

A total of 144 participants were recruited, evenly divided into the HMS ($n = 72$) and control ($n = 72$) groups. HMS participants were selected from rheumatology and physiotherapy clinics specializing in joint hypermobility, meeting the Brighton criteria, aged 18–50 years, and capable of providing informed consent. Exclusion criteria included recent major orthopedic surgery, significant musculoskeletal trauma, neurological disorders affecting balance or proprioception, pregnancy, or participation in other clinical trials.

Control group participants were recruited from the general community through advertisements and outreach programs and were matched for age. Age matching was performed using a group-wise approach, ensuring similar mean age and distribution across predefined age brackets (18–25, 26–35, 36–45, 46–50 years). This method facilitated balanced recruitment while maintaining comparability. They had no history or clinical signs of joint hypermobility, chronic pain, or musculoskeletal complaints. Identical exclusion criteria were applied for consistency. Purposive sampling ensured a representative cohort, with preliminary screening via interviews before obtaining written informed consent. HMS diagnosis was based on the Brighton criteria [2], which consider both joint hypermobility (assessed via the Beighton score) and additional clinical features. A Beighton score ≥ 4 indicated generalized joint hypermobility, but classification as HMS required meeting full Brighton criteria. Some control participants had scores > 4 but lacked other diagnostic criteria, while a few HMS participants had scores < 4 but exhibited qualifying musculoskeletal and systemic symptoms.

Bias and sampling errors were minimized through strict inclusion/exclusion criteria, multi-source recruitment, and demographic balancing. Standardized assessments by trained professionals ensured consistency and statistical validation confirmed group comparability. A structured screening proforma collected demographic data, medical history, musculoskeletal symptoms, prior diagnoses, and Beighton scores. HMS participants met Brighton criteria, while controls had no joint hypermobility or musculoskeletal disorders. Screening involved structured interviews and clinical evaluations.

Beighton score assessment

The Beighton Score, a widely used diagnostic tool for assessing joint hypermobility [12], played a critical role in including the study participants. This scoring system evaluates the flexibility of various joints, which is crucial for identifying individuals with HMS [12]. The assessment involves nine specific tests, each scoring one point for the presence of hypermobility: bending the thumbs to the forearm, extending the little fingers beyond 90 degrees, hyperextending the elbows and knees beyond 10 degrees, and touching the hands flat on the floor without bending the knees [13]. Participants were guided through each test by a trained professional, who ensured proper technique and safety. The total score ranges from 0 to 9, with higher scores indicating greater joint laxity. A threshold is typically set (a score of 4 or more) to classify individuals as hypermobile [13].

Limits of stability assessment

In this study, the LOS assessment was meticulously standardized to ensure the highest level of data accuracy and reliability [14]. The participants were first acclimatized to the testing setup, where they received comprehensive instructions on utilizing the Iso-free stabilometric force platform. Emphasis was placed on maintaining a relaxed yet stable posture to accurately assess their Center of Gravity (COG) shifts. The testing conditions were meticulously controlled - with optimal lighting, a consistent temperature, and a quiet environment - to provide ideal conditions for accurate LOS measurements. Participants were advised to wear comfortable attire that wouldn't hinder their movement, facilitating unrestricted COG shifts [14]. The force platform, a crucial component of our setup, was rigorously calibrated in line with the manufacturer's recommendations, ensuring precision in data gathering. During the assessment, participants were directed to shift their COG in eight predetermined directions (Fig. 1), displayed on a screen for visual guidance. The Iso-free system randomized these directions, enhancing the assessment's challenge by requiring focus and precise movement within specific time constraints. Participants had to return to a neutral stance after each movement, aided by computerized feedback, ensuring a consistent approach throughout the test.

To augment the reliability of the LOS measurements, we adopted a standardized protocol. Participants were asked to execute each COG shift in a controlled manner, avoiding balance loss or lifting their heels from the platform (Fig. 1). This procedure was repeated consistently for all eight directions, ensuring uniformity in the testing process. Further enhancing the assessment's reliability, each participant completed the LOS test three times. The trial with the best performance was chosen for detailed analysis. A rest period of one minute was included between each session to prevent fatigue, which could potentially affect the results.

Lumbar proprioception assessment

In this study, we employed a thorough and validated protocol to assess lumbar proprioception, a critical aspect involving the perception and control of the lumbar spine's position and movement [15]. Under the guidance of the examiners, who were well-trained in the assessment technique, participants were oriented with detailed instructions and engaged in a preliminary practice session. They began in a standard standing position, using a predefined target lumbar position as a reference point for the proprioceptive tasks.

Lumbar Joint Repositioning Error (JRE), a key indicator of proprioceptive acuity, was quantified in degrees across various movements: lumbar flexion, extension, and lateral bending to both sides. The assessment occurred in a controlled laboratory environment, ensuring tranquility and optimal ventilation. Participants were blindfolded during the JRE tests to isolate proprioceptive feedback. The Lumbar Proprioception Assessment method, recognized for its reliability and precision in measuring lumbar spine movements, was utilized. This method's robustness is well-documented, with correlation coefficients consistently ranging between 0.75 and 0.92 [15]. For the assessment, two inclinometers were strategically placed: the primary on the chest at the T12 level and the secondary on the hemipelvis at the S1 level for flexion and extension measurements (Fig. 2A). For lateral bending assessments, the primary inclinometer was positioned on the upper back at the T12 spinous process, and the secondary was on the sacrum (Fig. 2B). Participants' full range of motion in flexion, extension, and lateral bending was recorded, and half of this range was selected as the target position for repositioning tasks.

Participants were instructed to smoothly and precisely execute lumbar movements, including flexion, extension, and lateral bending in both directions. The assessment began with subjects standing upright to determine their

Fig. 1 Limits of stability assessment using Iso-free stabilometric force platform in eight directions

Fig. 2 Lumbar joint Joint Repositioning Error assessment using dual digital inclinometer. (A) JRE assessment in flexion, (B) JRE assessment in lateral bending right

self-selected neutral spine position. They were then gently guided by the examiner to reach the target position (50% of their ROM) for a brief duration of five seconds, which they were asked to memorize. After returning to the initial position, participants actively moved their lumbar spine back to this target position, signaling completion verbally. Lumbar JRE was calculated in degrees, quantifying the deviation between the achieved and target angles. The inclinometers recorded angular changes during each movement, and the data were meticulously collected for subsequent analysis. Each movement was replicated three times, and the mean of these trials was used to gauge the accuracy of lumbar repositioning.

All measurement devices were calibrated before each testing session following manufacturer guidelines. The stabilometric force platform was reset before every participant assessment, and digital inclinometers were zeroed before each use to ensure accuracy. These procedures minimized measurement errors and ensured data reliability.

Kinesiophobia assessment

Kinesiophobia, the irrational and debilitating fear of physical movement and activity often resulting from a feeling of vulnerability to painful injury or re-injury, was a pivotal parameter in our study [16]. To assess this, we employed the Tampa Scale for Kinesiophobia (TSK), a widely recognized and validated tool specifically designed to measure fear of movement [16]. The TSK is a 17-item questionnaire where participants rate their agreement with various statements related to physical activity and pain on a 4-point Likert scale, ranging from "strongly disagree" to "strongly agree." The scores from these items are then summed to provide an overall measure of Kinesiophobia, with higher scores indicating greater fear. Before administering the TSK, participants were given a thorough explanation of each item to ensure clear understanding. They were encouraged to reflect on their personal experiences with physical activity and pain while responding to the assessment to ensure its accuracy. The administration of the TSK was conducted in a quiet and comfortable environment to allow participants to concentrate fully on their responses. The reliability and validity of the TSK have been extensively established in various populations, including those with musculoskeletal disorders, making it a suitable tool for evaluating Kinesiophobia in individuals with Hypermobility Syndrome [17].

Table 1 Comparative demographic and clinical characteristics of individuals with HMS and control subjects

Characteristic	HMS Group ($n=72$)	Control Group ($n=72$)	*p*-Value
Age (years)	30.89 ± 5.76	31.35 ± 6.76	0.563
Sex (male/female)	22 (30.6%)/50 (69.4%)	24 (33.3%)/48 (66.7%)	0.735
BMI (kg/m^2)	24.56 ± 4.34	23.98 ± 3.34	0.458
Physical activity level (hours/week)	3.78 ± 1.54	3.58 ± 1.29	0.342
Kinesiophobia level (TSK)	35.34 ± 6.54	20.45 ± 3.56	< 0.001
Beighton score	5.46 ± 1.87	2.45 ± 1.35	< 0.001
Fatigue Severity Scale (FSS)	5.42 ± 1.77	2.56 ± 1.05	< 0.001
SF-36 Health Survey Score	38.39 ± 25.66	80 ± 15.56	< 0.001

The table presents mean ± standard deviation for continuous variables (age, body mass index (BMI), physical activity level, kinesiophobia level, Beighton score, Fatigue Severity Scale, and SF-36 Health Survey Score) and frequency (percentage) for categorical data (sex distribution)

Fatigue severity scale (FSS)

The FSS was utilized to quantify the level of fatigue experienced by participants, an essential aspect given its prevalence and impact in HMS [18]. The FSS is a self-administered questionnaire consisting of nine statements that assess the severity of fatigue symptoms and their effect on a person's daily activities [18]. Participants rate their agreement with each statement on a scale of 1 (strongly disagree) to 7 (strongly agree), with higher scores indicating more severe fatigue. The scale covers aspects such as physical functioning, exercise tolerance, and the impact of fatigue on work, family, or social life. This comprehensive approach ensures a thorough evaluation of fatigue's multifaceted nature. In our study, participants completed the FSS in a controlled setting, allowing them to focus on their responses without distractions. The FSS's reliability and validity have been established in various clinical populations, including those with chronic fatigue and musculoskeletal disorders, making it a suitable tool for assessing fatigue in individuals with HMS [19].

Data analysis

The data followed a normal distribution when tested with the Shapiro-Wilk test for each variable. Independent t-tests were utilized to compare mean differences in LOS and proprioception scores between the two groups. Where multiple comparisons were necessary, a Bonferroni correction was applied to adjust the significance levels. For the second objective, the relationship between LOS and lumbar proprioception within HMS individuals was evaluated using Pearson's correlation coefficient. A structural equation modeling approach was utilized to estimate the direct and indirect effects within our proposed mediation framework. Path coefficients were computed to assess the strength and direction of the relationships between the variables. All statistical analyses were conducted using the SPSS software (24.0 version). The alpha level for all tests was set at 0.05, with adjustments for multiple comparisons made as necessary.

Results

Demographic comparisons between the HMS and control groups showed no significant differences in age, sex distribution, BMI, or physical activity levels, ensuring comparability (Table 1). However, individuals with HMS exhibited significantly higher Kinesiophobia levels, Beighton scores, and fatigue severity while reporting lower quality of life, as measured by the SF-36 survey ($p < 0.001$ for all). These findings highlight the substantial

Table 2 Limits of stability and lumbar proprioception between group comparisons

Characteristic	HMS Group (*n* = 72)	Control Group (*n* = 72)	*P*-Value	Mean Difference	Cohen's d
LOS - Forward (%)	40.18 ± 4.67	77.87 ± 8.97	< 0.001	37.69	5.27
LOS - Right-Forward (%)	67.89 ± 7.89	87.98 ± 10.87	< 0.001	20.09	2.12
LOS - Right (%)	71.05 ± 11.23	91.27 ± 11.23	< 0.001	20.22	1.80
LOS - Right-Backward (%)	88.88 ± 13.45	96.67 ± 13.56	< 0.001	7.79	0.58
LOS - Backward (%)	86.23 ± 12.22	94.24 ± 11.25	< 0.001	8.01	0.68
LOS - Left-Backward (%)	78.45 ± 9.98	89.97 ± 10.98	< 0.001	11.52	1.10
LOS - Left (%)	83.37 ± 9.78	93.67 ± 12.34	< 0.001	10.30	0.93
LOS - Left-Forward (%)	87.34 ± 11.23	96.89 ± 13.45	< 0.001	9.55	0.77
LOS - Total Objective (%)	77.93 ± 9.87	95.67 ± 11.34	< 0.001	17.74	1.67
Proprioception Error- Flexion (°)	4.03 ± 1.07	2.94 ± 0.81	< 0.001	-1.09	-1.15
Proprioception error - Extension (°)	4.63 ± 1.86	2.88 ± 0.64	< 0.001	-1.75	-1.26
Proprioception Error- Lateral Bending Left (°)	5.42 ± 0.90	2.58 ± 0.74	< 0.001	-2.84	-3.45
Proprioception Error - Lateral Bending Right (°)	5.86 ± 0.78	2.98 ± 0.99	< 0.001	-2.88	-3.23

LOS: Limits of Stability, HMS: Hypermobility syndrome

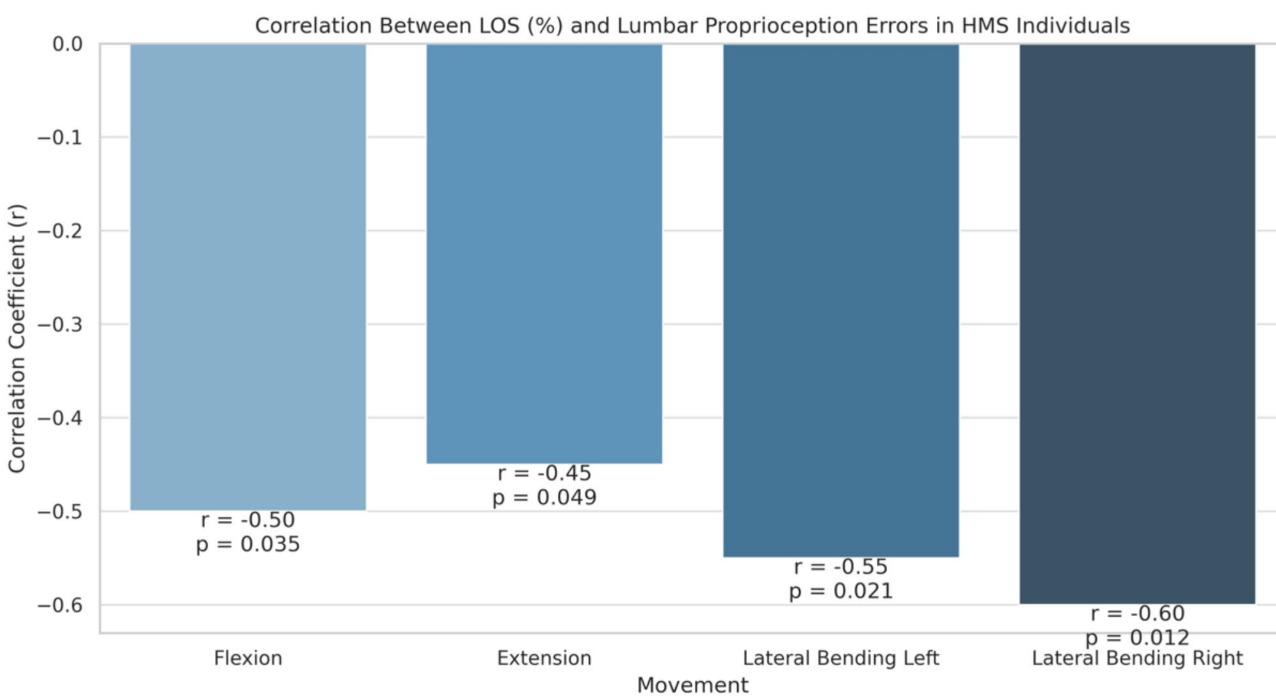

Fig. 3 Correlation between LOS (%) and Lumbar Proprioception Errors in Hypermobility Syndrome Individuals

clinical burden associated with HMS, particularly in psychological and physical health domains.

HMS individuals demonstrated significantly lower LOS across all directions compared to controls, indicating substantial deficits in balance and stability ($p < 0.001$ for all) (Table 2). The large effect sizes (Cohen's d: 0.58–5.27) highlight the magnitude of these impairments. Additionally, proprioception errors in flexion, extension, and lateral bending were significantly higher in the HMS group, with mean differences ranging from – 2.84° to -1.09° ($p < 0.001$). Large effect sizes (Cohen's d: -1.15 to -3.45) further emphasize the extent of proprioceptive dysfunction in HMS, reinforcing its impact on postural control.

Correlation analysis revealed moderate negative correlations between LOS and lumbar proprioception errors across flexion, extension, and lateral bending movements in HMS individuals (Fig. 3). Lower LOS was associated with higher proprioception errors, indicating that decreased stability corresponds with impaired proprioceptive accuracy.

The mediation analysis (Table 3; Fig. 4) demonstrated that Kinesiophobia and fatigue significantly influence the relationship between LOS and proprioception in HMS. Higher LOS was associated with increased Kinesiophobia and fatigue, both of which negatively impacted proprioception. Significant indirect pathways indicated that

Table 3 Mediation analysis of psychological and physical factors in hypermobility syndrome

Path	Coefficients	Standard Error	*p*-value
LOS -> Kinesiophobia	0.40	0.08	0.015
Kinesiophobia -> Proprioception	-0.35	0.07	0.023
LOS -> Fatigue	0.45	0.09	0.035
Fatigue -> Proprioception	-0.30	0.06	0.012
LOS -> Proprioception	-0.50	0.10	0.014
LOS -> Kinesiophobia -> Proprioception	Indirect: -0.14	0.05	0.049
LOS -> Fatigue -> Proprioception	Indirect: -0.135	0.045	0.047

LOS: Limits of Stability, Path: The specific relationship being analyzed, Coefficients: The strength and direction of the relationship, Standard Error: The standard error of the coefficient

LOS affects proprioception through these mediators, highlighting the need to address both psychological and physical factors in HMS management.

Discussion

This study examined differences in LOS and lumbar proprioception between HMS and control groups, the correlation between LOS and proprioception errors in HMS, and the mediating effects of Kinesiophobia and fatigue. Results showed that HMS individuals had significantly lower LOS and higher proprioception errors than controls, indicating impaired balance and proprioceptive function. Moderate negative correlations between LOS and proprioception errors suggest that reduced stability is linked to proprioceptive inaccuracies in HMS. Mediation analysis confirmed that Kinesiophobia and fatigue significantly influence proprioception, highlighting the combined impact of physical and psychological factors on motor control. These findings emphasize the need for

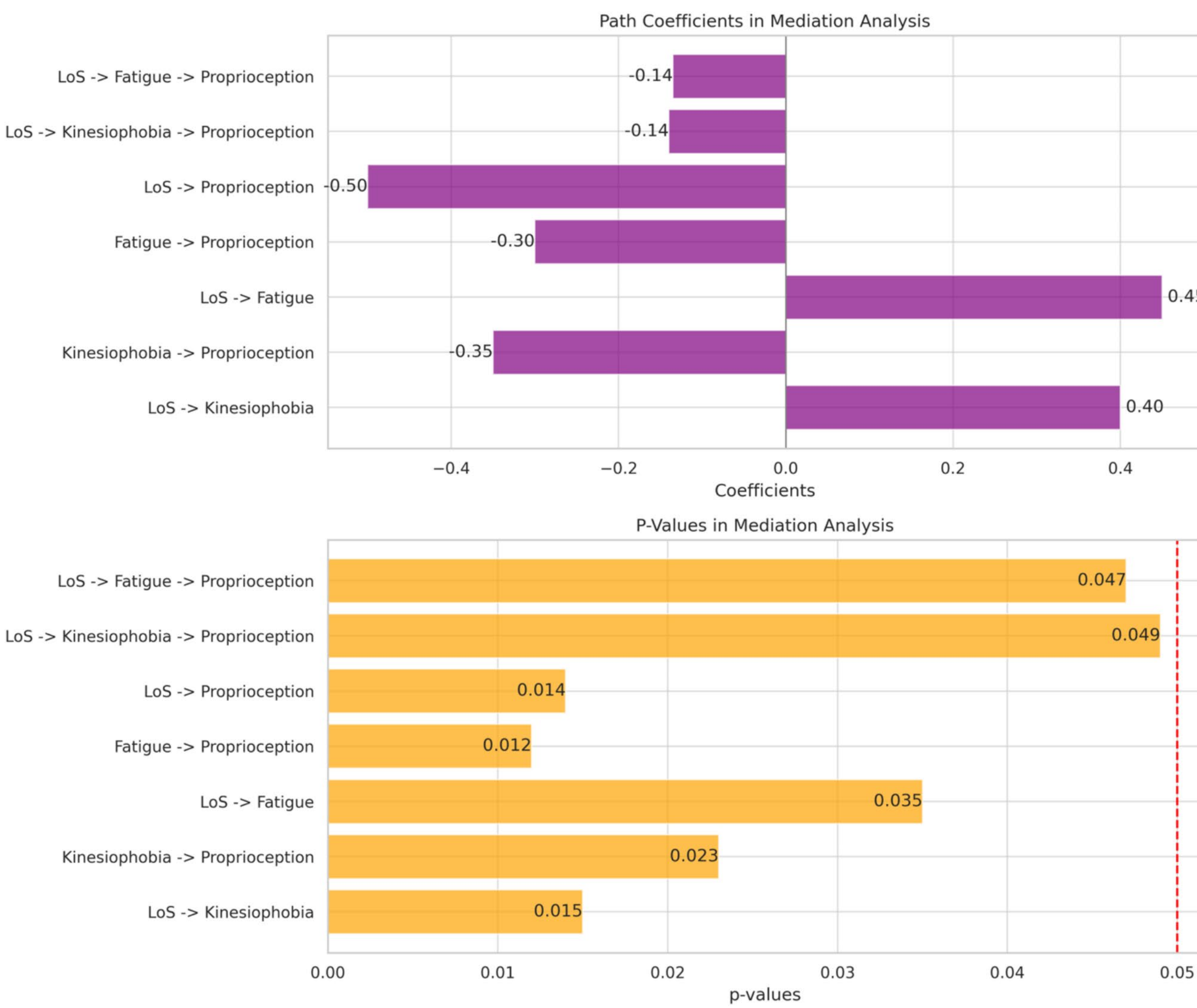

Fig. 4 Path Coefficients and *P*-Values in the Mediation Analysis of LOS, Kinesiophobia, Fatigue, and Proprioception in HMS

targeted interventions addressing both stability and psychological contributors in HMS management.

The reduced LOS and increased lumbar proprioception errors in HMS individuals compared to controls are primarily due to joint hypermobility, which leads to instability and impaired balance [20]. Connective tissue abnormalities disrupt proprioceptive feedback, increasing sensory inaccuracies, while chronic pain and fatigue further compromise motor control and postural stability [21]. These factors collectively contribute to significant deficits in balance and proprioception, reinforcing the impact of HMS on functional mobility [22]. Previous research supports the findings of this study, underscoring the impact of joint hypermobility and associated symptoms on balance and proprioception [23, 24]. Studies have consistently shown that individuals with HMS exhibit poorer balance control and increased postural sway compared to those without the condition [23]. A study by Bates et al. [23] reported that individuals with HMS showed significantly lower balance scores across various tests compared to controls. These studies align with the current findings, highlighting the pronounced deficits in LOS and lumbar proprioception among individuals with HMS.

The negative correlation between LOS and lumbar proprioception errors in HMS individuals reflects the impact of joint hypermobility on postural stability [25]. Increased joint laxity leads to reduced stability, particularly in challenging positions such as flexion, extension, and lateral bending, increasing reliance on proprioceptive mechanisms [26]. However, altered joint mechanics and sensory deficits impair proprioceptive accuracy, resulting in higher proprioception errors as LOS decreases [27, 28]. This relationship highlights the functional impact of joint instability on balance control in HMS. Previous studies have provided insights that support these findings. Research has consistently shown that joint hypermobility, a hallmark of HMS, is associated with deficits in proprioceptive accuracy. A study by Reddy et al. [29] found that individuals with joint hypermobility syndrome exhibited significantly higher proprioceptive errors compared to those without the syndrome [29]. Additionally, research focusing on balance in HMS populations, such as the work by Akkaya et al. [30], has demonstrated decreased stability and increased postural sway in these individuals. The moderate negative correlations observed in the current study across various movements align with these previous findings, highlighting the interconnected nature of balance and proprioceptive accuracy in HMS [31]. The results emphasize the need for a comprehensive approach in HMS management, addressing both the mechanical aspects of joint stability and the sensory aspects of proprioception to improve overall function and quality of life for these individuals.

The mediation analysis demonstrated that Kinesiophobia and fatigue significantly influence the relationship between LOS and proprioception in HMS [32]. Greater instability and balance deficits were associated with increased Kinesiophobia, which negatively impacted proprioception by limiting movement and proprioceptive feedback [33]. Similarly, maintaining stability requires increased physical effort, leading to fatigue, which further impairs neuromuscular control and proprioceptive sensitivity [34]. These findings highlight that proprioceptive errors in HMS are not solely due to mechanical instability but are also shaped by psychological and physiological responses.

Clinical significance

This study highlights the clinical significance of HMS by demonstrating substantial deficits in LOS and lumbar proprioception, underscoring its impact on balance, functional mobility, and quality of life. The observed correlations between LOS and proprioception errors, along with the mediation effects of Kinesiophobia and fatigue, emphasize the intricate interaction between physical and psychological factors. These findings reinforce the need for integrated therapeutic approaches that address both joint instability and proprioceptive impairments while considering psychological contributors such as fear of movement. A multidisciplinary management strategy may enhance functional outcomes and reduce fall risk in individuals with HMS.

Limitations of the study

This study has certain limitations that should be acknowledged. Its cross-sectional design limits the ability to establish causal relationships, highlighting the need for longitudinal studies to assess the progression of symptoms and long-term effects of HMS on balance and proprioception. The reliance on quantitative assessments may not fully capture the subjective experiences of individuals with HMS, suggesting that future research should incorporate qualitative measures for a more comprehensive understanding. Variability in symptom severity among participants could have influenced the results despite standardized assessment conditions. Additionally, the generalizability of findings may be restricted due to the specific demographic characteristics of the study sample, underscoring the need for more diverse participant recruitment. While efforts were made to minimize bias through strict inclusion criteria, multi-source recruitment, and demographic matching, the purposive sampling method may introduce selection bias. Furthermore, despite standardized protocols and trained professionals ensuring assessment consistency, observer bias cannot be entirely ruled out. Future studies should consider random sampling methods to enhance generalizability and reduce potential biases.

Conclusion

This study demonstrates that individuals with HMS have significant deficits in LOS and lumbar proprioception compared to controls, indicating compromised postural control and proprioceptive accuracy. Moderate negative correlations between LOS and proprioception errors highlight the impact of joint hypermobility on balance maintenance. Mediation analysis confirms that Kinesiophobia and fatigue significantly influence this relationship, underscoring the interplay between physical impairments and psychological factors. These findings emphasize the need for a comprehensive management approach that targets both postural stability and proprioceptive function while addressing psychological contributors to movement limitations.

Abbreviations

HMS	Hypermobility Syndrome
LOS	Limits of Stability
TSK	Tampa Scale of Kinesiophobia
COG	Center of Gravity
JRE	Joint Repositioning Error
FSS	Fatigue Severity Scale

Supplementary Information

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Supplementary Material 1

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Author contributions

Conceptualization, MAA and RSR; methodology, MAA and RSR; formal analysis, MAA and RSR; investigation, MAA and RSR; data curation, MAA and RSR; writing—original draft preparation, MAA and RSR; writing—review and editing, MAA and RSR; funding acquisition, RSR. Both authors have read and agreed to the final version of the manuscript for publication.

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Data availability

The dataset related to this study has been archived in the publicly accessible "Zenodo" repository. It can be accessed using the following DOI: [10.5281/zenodo.10784498] (https://doi.org/10.5281/zenodo.10784498).

Declarations

Ethics approval and consent to participate

The study was conducted following the Declaration of Helsinki and approved by the Institutional Review Board at King Khalid University (protocol code: ECM# 2021–4404) and date of approval: 10-03-2021)." for studies involving humans.

Consent for publication

All participants in the present study received instructions about the experimental procedures and content, and the experiments were conducted after they had completed the consent forms.

Competing interests

The authors declare no competing interests.

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