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Original Article

Postural balance control in women with generalized joint laxity

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ABSTRACT

Objectives: This study aims to investigate the potential relationship between joint laxity and postural balance by using tetra-ataxiometric posturography (Tetrax®).

Patients and methods: A total of 69 healthy volunteers were included in the study and classified into three groups based on their hypermobility severity determined with Beighton-Horan hypermobility index scores. Of those, 29 participants were non-hypermobile, 13 participants were mildly hypermobile and remaining 27 patients had severe hypermobility. Postural control of the participants was evaluated by using the Tetrax® device in eight different positions. The stability index, Fourier index, weight distribution index, and synchronization index scores of each participant were recorded.

Results: We found that the participants with severe hypermobility exhibited significantly higher stability index scores while the position of the head is extended and rotated right. The weight distribution index on elastic surfaces was impaired in non-hypermobile and severely hypermobile participants. We observed that the Fourier Index scores were higher at a higher-medium frequency (0.5-1 Hz) in participants with severe hypermobility. There was no difference between the groups in terms of synchronization index scores.

Conclusion: These findings suggest that severely hypermobile individuals have a decreased postural stability in head-extended and head-rotated positions when compared to individuals who are non-hypermobile. This increased instability may lead to an increased risk of musculoskeletal injuries, especially in sports that require extension and rotation movements of the head.

Keywords: Balance control; hypermobility; posturography.

Generalized joint laxity (GJL) refers to a condition characterized by ranges of joint motion beyond the normal limits. Familial tendency, young age, female gender and excessive stretching in sports have been reported to be associated with GJL.[1,2] This entity is described as benign, due to the absence of any underlying rheumatologic or hereditary disease. On the other hand, the prevalence of musculoskeletal complaints, such as arthralgia, recurrent subluxations or dislocations and injuries has been found to be higher in individuals with hypermobile joints.[3,4]

Balance control is an important ability in daily tasks. To maintain balance control, several aspects of the human body work together such as, the visual and vestibular systems, muscle strength and proprioception.[5,6] Previous studies have demonstrated that people with hypermobile joints have an altered proprioception, which is mostly evident in knee joints and proximal interphalangeal joints.[7-9] Individuals with joint hypermobility have also demonstrated decreased knee muscle strength, which may also impact the balance control.[10]

Tetra-ataxiometric posturography Tetrax® (Sunlight Medical Ltd., Ramat Gan, Israel) is a diagnostic tool for assessing balance problems and risk of falling. This device measures balance and stability by recording vertical pressure fluctuations on four independent and integrated force platforms; left and right fore-foot and rear-foot. To test the balance, Tetrax® measures the

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reaction of the person to different positions such as, with/without visual input, different head positions and different platform surfaces. In addition to calculating the risk of falling, the Tetrax® device can provide information about the risk factors associated with falling.

Impaired balance control in individuals with GJL has been reported in a number of studies.[11-13] However, there is no available study on the detection of balance problems through the analyses of a variety of postural variables. Therefore, the purpose of this study is to investigate potential differences in balancing ability among non-hypermobile, mildly hypermobile and distinctly hypermobile participants, using tetra-ataxiometric posturography.

PATIENTS AND METHODS

This cross-sectional survey was conducted with 69 healthy volunteers between 16 and 25 years of age, who were recruited from the students and employees of the Adnan Menderes University Training and Research Hospital between September 2014 - September 2015. The Adnan Menderes University Faculty of Medicine Non Interventional Clinical Research Ethics Committee approved the study (2015/534) and all participants provided their written informed consent to participate in the study. The study was conducted in accordance with the principles of the Declaration of Helsinki. Exclusion criteria consisted of orthopedic or neurological impairments, pain, visual, vestibular and cognitive disorders, history of a lower extremity surgery or acute trauma.

The Beighton-Horan joint mobility index (BHJMI) was used to determine the severity of hypermobility. The BHJMI is the most common diagnostic tool for GJL, which consist of five different laxity tests.[14-16] The BHJMI is easy to administer and needs no special equipment other than a goniometer. The overall composite scores of the index range from 0 to 9 and are placed into three categories: 0 to 2 as not hypermobile, 3 to 4 as moderately hypermobile, with 5-9 being distinctly hypermobile.[16]

There are five maneuvers to determine the BHJMI: *(i) Fifth finger hyperextension test:* upper extremity of the participant is stabilized on the table with the forearm in full pronation. The investigator passively extends the participant's fifth finger until pain arises. Passive dorsiflexion beyond 90˚ results in a score of 1. *(ii) Elbow hyperextension test:* the amount of extension of the elbow joint is measured using a goniometer. Hyperextension of the elbow beyond 10˚ resulted in a score of 1. *(iii) Thump opposition test:* participants flex their wrist and stretch their thump towards the forearm. Passive dorsiflexion of the thump to the flexor aspect of the forearm results in a score of 1. *(iv) Knee hyperextension test:* participants are instructed to bend forward with their both knees extended. The amount of knee extension is measured using a goniometer. Hyperextension beyond 10˚ results in a score of 1. *(v) Palms to floor test:* participants are instructed to bend forward and try to touch the floor with their both knees extended. If the palms and hands rest on the floor, a score of 1 is given.

All the maneuvers were done bilaterally except palms to floor test. The participants were divided into three groups according to their BHJMI score calculated as described above (0-2, 3-4 and 5-9).

Static posturography was performed in a quiet room using a Tetrax® device, which was connected to a personal computer. The device was calibrated before the study. The patients placed their feet barefoot on

Table 1. Positions of assessment in tetra-ataxiometry and their purpose

	Positions	Purpose
NO	Neutral head position, eyes open, firm surface	Basic position
NC	Neutral head position, eyes closed, firm surface	Elimination of the visual system
PO	Neutral head position, eyes open, elastic surface	Elimination of somatosensory system
PC	Neutral head position, eyes closed, elastic surface	Elimination of somatosensory and visual systems
HR	Head turned right about 45˚, eyes closed, firm surface	Vestibular stress and elimination of visual system
HL	Head turned left about 45˚, eyes closed, firm surface	Vestibular stress and elimination of visual system
HB	Head raised backward about 30˚, eyes closed, firm surface	Cervical and vestibular stress and elimination of the visual system
HF	Head bended forward about 30˚, eyes closed, firm surface	Cervical and vestibular stress and elimination of the visual system

NO: Normal position with eyes open; NC: Normal position with eyes closed; PO: Eyes open on pillows; PC: Eyes closed on pillows; HR: Head turned right and eyes closed; HL: Head turned left and eyes closed; HB: Eyes closed head positioned backward 30°; HF: Eyes closed head positioned forward 30°.

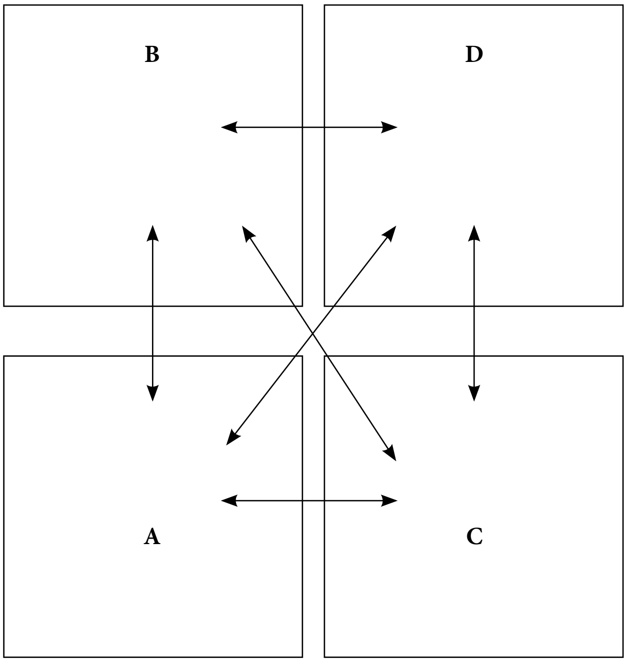

Figure 1. Schematic diagram of six synchronization measures. The distribution of four plates was as follows. Plate A: Left rearfoot; Plate B: Left forefoot; Plate C: Right rearfoot; Plate D: Right forefoot.

four force plates (A, left heel; B, left toes; C, right heel; D, right toes) with arms at the side along the body and were asked to remain in the standing position, stable and immobile in eight different positions for 32 sec (Table 1). The data recorded by each force plate was analyzed by the Tetrax® software program. Fourier index, fall index, stability index, weight distribution index and synchronization index parameters were assessed.

Fourier Index (FI): The FI is an analysis of postural sway in a scale of rising frequency bands. Tetrax® software subdivides the frequency of postural sway into four categories; F1: low frequencies (below 0.1 Hz), F2-4: lower medium frequencies (0.1-0.5 Hz), F5-F6: higher medium frequencies (0.5-1 Hz), and F7-F8: high frequencies (above 1 Hz). Normal postural performance is characterized by a high intensity in the low frequency range. This indicates that posture is controlled by an intact visual, vestibular input and a good postural feedback system. A high FI at F2-4 signifies a vestibular impairment or fatigue of the musculoskeletal system. Increased sway at higher medium frequency (0.5-1 Hz) reflects somatosensory response mediated by the motor function of the lower extremities, the spine and the lower back. Fluctuation at a high frequency (above 1 Hz), indicates a postural instability due to central nervous system abnormality.[17]

Stability index (ST): The ST indicates the general stability, which measures the amount of sway over the four integrated platforms. This parameter is not associated with the individual's weight and height. Higher index scores reflect more unstable posture.[18]

Weight distribution index (WDI): The WDI reflects the level of weight distribution between four platforms. The normal percentage of weight distribution on each platform is 25%, with a normal index being 4 to 6.[19]

Synchronization index (SI): The synchronization index evaluates the coordination between the heel and the toes of each foot (AB, CD), between the two heels and the toes of both feet (AC, BD), between the heel of one foot with the contralateral foot toes (AD, BC) (Figure 1). Oscillation waves recorded from the body vibrations of four plates gives values that can vary between - 1000 and 1000. In normal participants, absolute values are approximately 700 and SI between heel and toe plates (AB, CD) of the same foot is a negative value. Synchronization index between the right and left lower extremities (AC, BD) results in a positive value.[18]

Statistical analysis

Statistical analyses were performed using the IBM SPSS version 20.0 software (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to assess the normality of numeric variables. Homogenity of the variances were checked with Levene test. For the numeric variables that were normally distributed, comparison between three groups was made by one way ANOVA (Tukey test was used for post hoc test) and descriptive statistics are presented as mean (standard deviation). For the numeric variables that were not normally distributed,

Table 2. Demographic variables of the participants

	Group 1 (n=29)	Group 2 (n=13)	Group 3 (n=27)	
	Mean±SD	Mean±SD	Mean±SD	*p*
Age (year)	21.6±3.4	21.2±2.8	20.8±2.9	0.678*
Body mass index (kg/m^2)	20.9±3.3	22.2±4.8	21.1±4.3	0.601*

SD: Standard deviation; * One way ANOVA was used. P values less than 0.05 considered statistically significant.

Table 3. Comparison of stability index scores among the groups

	Group 1 (n=29)			Group 2 (n=13)			Group 3 (n=27)			
	Mean±SD	Median	Min.-Max.	Mean±SD	Median	Min.-Max.	Mean±SD	Median	Min.-Max.	*p*
NO		11.34	8.85-14.54		12.06	9.67-16.83		12.36	10.14-14.35	0.641‡
NC	15.7±6.0			16.0±5.1			18.6±7.4			0.205†
PO		14.34	11.67-17.02					14.68	12.11-17.23	0.756‡
PC	22.0±7.2			24.2±8.2			26.3±9.3			0.149†
HR	14.6±5.5			17.6±5.3			18.3±6.0*			0.046†
HL		15.60	11.93-21.51		14.45	13.02-22.03		18.58	13.26-23.71	0.383‡
HB		15.03	13.11-21.70		18.67	17.00-21.94		20.83	16.90-26.90**	0.041‡
HF		16.88	13.41-21.58		17.80	12.85-19.70		18.89	14.79-24.89	0.362‡

SD: Standard deviation; Min.: Minimum; Max.: Maximum; NO: Normal position with eyes open; NC: Normal position with eyes closed; PO: Eyes open on pillows; PC: Eyes closed on pillows; HR: Head turned right and eyes closed; HL: Head turned left and eyes closed; HB: Eyes closed head positioned backward 30°; HF: Eyes closed head positioned forward 30°.
Median (25^{th}-75^{th} percentiles) as indicated. † One way ANOVA (Tukey test for post hoc analysis) and ‡ Kruskal Wallis (Dunn's test for post hoc analysis) were used as indicated. * p=0.044 between group 1 and group 3; **p=0.038 between group 1 and group 3; *P* values less than 0.05 was considered statistically significant.

comparison between two groups was made by Kruskal Wallis test (Dunn's test was used for post hoc test) and descriptive statistics are presented as median (25-75 percentiles). Bonferroni correction was made and obtained, a *p* value of <0.05 was considered statistically significant.

RESULTS

There were no statistically significant differences among the groups in terms of baseline demographic characteristics (Table 2).

Stability index: The distinctly hypermobile group had a significantly higher mean ST score than the non hypermobile group in head right turned and head backward positions. In closed eye positions, the mean ST scores were increasing with increasing degrees of hypermobility. In open eye positions, no difference was found among the groups in the mean ST scores (Table 3).

Weight distribution index: As shown in Table 4, the groups did not show any statistically significant difference regarding WDI. All groups' WDI values were in normal ranges in all positions on firm surfaces, but not on elastic surfaces The WDI scores on elastic surfaces were beyond normal limits in participants who are not hypermobile and participants who are distinctly hypermobile (Table 4).

Synchronization index: There was no significant difference in terms of SI scores among non-hypermobile, moderately hypermobile and distinctly hypermobile participants.

Table 4. Comparisons of weight distribution index scores among the groups

	Group 1 (n=29)			Group 2 (n=13)			Group 3 (n=27)			
	Mean±SD	Median	Min.-Max.	Mean±SD	Median	Min.-Max.	Mean±SD	Median	Min.-Max.	*p*
NO	5.6±2.7			6.1±2.9			6.2±3.4			0.753†
NC		4.87	3.76-5.74		5.72	3.23-7.29		6.46	2.45-8.16	0.386‡
PO	9.2±4.6			6.6±3.9			9.7±4.4			0.114†
PC	8.0±4.1			5.4±2.7			8.2±3.9			0.086†
HR	5.4±2.8			6.6±2.7			5.4±3.4			0.461†
HL	5.7±2.6			6.9±3.1			5.7±3.4			0.432†
HB		5.56	3.71-8.63		6.15	4.32-7.90		5.66	4.48-7.80	0.916‡
HF	5.4±2.7			6.3±3.1			5.0±3.0			0.427†

SD: Standard deviation; Min.: Minimum; Max.: Maximum; NO: Normal position with eyes open; NC: Normal position with eyes closed; PO: Eyes open on pillows; PC: Eyes closed on pillows; HR: Head turned right and eyes closed; HL: Head turned left and eyes closed; HB: Eyes closed head positioned backward 30°; HF: Eyes closed head positioned forward 30°.
Median (25^{th}-75^{th} percentiles) as indicated. † One way ANOVA (Tukey test for post hoc analysis) and ‡ Kruskal Wallis (Dunn's test for post hoc analysis) were used as indicated. *P* values less than 0.05 was considered statistically significant.

Table 5. Comparisons of Fourier index scores among the groups

	Lower medium frequency (0.1-0.5 Hz, F2-4)				Higher medium frequency (0.5-1.0 Hz, F5-6)				High frequency (>1.0 Hz, F7-8)			
	Group 1 (n=29)	Group 2 (n=13)	Group 3 (n=27)	*p*	Group 1 (n=29)	Group 2 (n=13)	Group 3 (n=27)	*p*	Group 1 (n=29)	Group 2 (n=13)	Group 3 (n=27)	*p*
NO	20.74 (14.95-24.99)	20.38 (16.76-34.77)	19.27 (16.16-27.69)	0.784¥	4.64 (3.61-5.88)	5.29 (3.47-5.73)	4.66 (3.95-5.95)	0.947¥	0.85 (0.67-1.12)	0.91 (0.69-1.33)	0.92 (0.73-1.11)	0.926¥
NC	20.32 (17.70-26.51)	26.64 (17.46-35.78)	25.55 (17.66-31.55)	0.291¥	5.80±2.28	5.54±1.93	7.38±3.31	0.061t	1.01±0.48	0.90±0.37	1.17±0.50	0.206t
PO	20.80 (15.45-27.52)	28.18 (17.74-39.10)	22.00 (17.47- 24.60)	0.352¥	5.19 (4.34-6.90)	6.77 (5.10-8.71)	5.66 (4.87-7.30)	0.240¥	1.04 (0.72-1.52)	1.19 1.11 1.53	1.08 (0.80-1.38)	0.197¥
PC	32.54 (23.58-39.83)	32.03 (24.59-41.84)	35.96 (29.50-41.90)	0.602¥	7.33 (6.07-10.40)	7.75 (5.96-11.91)	9.29 (6.82- 13.48)	0.078¥	1.25 (0.88-1.66)	1.29 (1.02-1.76)	1.29 (1.07-1.97)	0.435¥
HR	19.12 (15.14-28.38)	25.42 (21.01-36.35)	25.33 (20.31-31.67)	0.082¥	5.47±2.29	6.44±2.47	7.06±2.80	0.069t	0.86±0.36*	1.10±0.41	1.14±0.53*	0.045t
HL	21.01 (16.04-27.51)	22.74 (18.56-30.32)	23.30 (19.90-28.58)	0.372¥	4.64 (3.61-5.88)	5.29 (3.47-5.73)	4.66 (3.95-5.95)	0.947¥	0.84 (0.68- 1.37)	1.01 (0.76- 1.17)	1.18 (0.78-1.41)	0.222¥
HB	25.39±10.25	27.23±8.18	30.90±10.58	0.126t	5.90 (4.26-7.41)	6.91 (5.87-7.63)	6.92 (5.62-10.51)	0.108¥	1.15 (0.77-1.48)	1.25 (1.10-1.37)	1.22 (0.90-1.68)	0.333¥
HF	25.05 (18.33-31.20)	22.07 (17.74-31.82)	27.44 (20.81-32.79)	0.461¥	5.99 (3.86-7.65)	6.19 (4.89-6.64)	7.35 (6.10-9.62)	0.057¥	1.12 (0.71-1.47)	1.02 (0.86-1.22)	1.25 (1.01-1.63)	0.111¥

Values are mean (standard deviation) or median (25^{th}-75^{th} percentiles) as indicated. t One way ANOVA (Tukey test for post hoc analysis) and ¥ Kruskal Wallis (Dunn's test for post hoc analysis) were used as indicated; * p=0.047 between group 1 and group 3; *P* values less than 0.05 considered statistically significant.
NO: Normal position with eyes open; NC: Normal position with eyes closed; PO: Eyes open on pillows; PC: Eyes closed on pillows; HR: Head turned right and eyes closed; HL: Head turned left and eyes closed; HB: Eyes closed head positioned backward 30°; HF: Eyes closed head positioned forward 30°.

Fourier index: The FI showed a higher instable posture in the distinctly hypermobile group than the non-hypermobile group in the HR position of F7-8 (>1.0 Hz). In other positions and frequencies the FI did not significantly differ among the three groups. However, in higher medium frequency (0.5-1.0 Hz), increased FI values were observed in the distinctly hypermobile group compared to those of the non-hypermobile group (Table 5).

DISCUSSION

The results of the present study revealed increased ST values which indicate a mild impairment of static balance in females with GJL compared to participants without hypermobility. This impairment was more evident in head-right rotated and head-backward bent positions. Similarly, Iatridou et al.[13] found significant changes in balance control of individuals with joint hypermobility in the eyes open and head extended position. When a subject bends their head backward, vestibular stress and cervical stress are applied. In our study, participants were deprived of visual feedback. This position is sensitive to vestibulo-cervical disturbances.[20] Iatridou et al.[13] attributed their results to provoked orthostatic hypotension as a result of autonomic dysfunction that previously described in individuals with GJL.[21] While there is no evidence regarding an association between vestibular disorders and joint hypermobility, similar results between two studies are challenging.

In addition to vestibular pathologies, balance impairment in head extended position can arise from stretching of cervical muscles. There are high densities of muscle spindles in the cervical region[22] and cervical afferents are involved in tonic neck reflex to maintain postural stability.[23] Poor proprioceptive signals derived from knee receptors are known to impair the balance in patients with GJL.[7,8,12,24] As GJL has a widespread impact on all body parts, somatosensorial input derived from cervical muscles may also be affected. Therefore, balance control problems that appear in head-extended position are not surprising when the decreased proprioception in individuals with GJL is also taken into account.[7,25] The higher FI values that we observed at high medium frequency also indicated an altered somatosensory response due to the impaired motor function of the lower extremities and spine. Therefore, the balance deficit that we detected is likely to arise from the somatosensorial impairment rather than the vestibular impairment.

Tetrax ST is a mathematical expression of the amount of postural sway. In line with our findings, increased sway amplitudes of velocity have been found in earlier studies. Ferrell et al.[8] found that the values of mediolateral (ML) and anteroposterior (AP) sway while standing on a wobble board were higher in patients with joint hypermobility syndrome than in controls. They consider this balance impairment as a result of decreased proprioception that they previously described.[24] In addition, Rombaut et al.[11] investigated balance deficits in patients with Ehlers-Danlos Syndrome, which also includes general joint hypermobility as a feature. The authors found increased ML and AP sway when standing with eyes closed on a firm surface, eyes open on an elastic surface, and heel-to toe standing. In the same population, Galli et al.[26] found higher ML and AP excursions than the control group in eyes open and eyes closed conditions. In participants with GJL higher stability index values than we detected in head-rotated and head-extended positions indicate an increased postural sway and accordingly impaired balance control in this group.

There could be several other mechanisms that might interact with balance within people with joint laxity. In literature, muscle weakness and fatigue has been found to be associated with alterations in balance.[6,27] It is also known that people with joint laxity have decreased knee extensor muscle strength and increased levels of fatigue.[10,28] Besides vestibular pathologies, decreased proprioception, it is likely that muscle weakness and fatigue may also contribute to the balance impairment.

In addition to joint hypermobility, hypomobility may also impact balance control. In a previous study, Vergara et al.[29] found a significant displacement of the pressure center in the frontal plane in patients with ankylosing spondylitis. They concluded that the increased mechanical stiffness of the entire joints can be a contributing factor to altered postural control.[29] In the present study, weight distribution between right and left feet, between fore-foot and rear-foot is also found beyond normal value limits.[4-6] on elastic surfaces both in the non-hypermobile group and in the distinctly hypermobile group. However, mildly hypermobile participants had normal weight distribution in all positions and on both surfaces (firm or elastic). These findings suggest that a small amount of flexibility is needed for proper postural control of the body.

Most of the force plate studies evaluating balance have been limited while assessing interactions between two feet, as they used only one force platform. Using four force plates of tetra-ataxiometry gave us the opportunity of a more detailed evaluation of balance in humans, as a biped. In the present study, synchronization between the forefoot/rearfoot and right foot/left foot was found within normal limits and there were no differences between the groups. The harmony between and within the feet were intact in all positions which suggests, postural control ability of the foot was not affected with increasing joint mobility.

From a clinical perspective, our findings indicate that people with distinct GJL are more unstable under head-extended and head-rotated conditions. This instability may have noticeable implications in the development of musculoskeletal injuries. Especially sports involving sudden extension and rotation movements of the head, such as basketball and volleyball may be associated with an increased risk of injury. Physicians, physiotherapists and trainers are advised to evaluate joint hypermobility before prescribing exercise. To prevent injury, balance exercises (precisely in different head postures) should be included in the exercise routine for distinctly hypermobile individuals.

There are a number of limitations for this study. Firstly, we did not perform power analysis before the study as; this is the first study evaluating balance with tetra-ataxiometry in participants with joint laxity. Low power is the major limitation of the study. Secondly, clinical examination of balance and muscular strength were not performed. Clinical evaluation of the balance with reliable tools such as, Berg balance scale or time up-to go test would be useful in understanding the possible impact of balance deficits in daily activities. However, these tools may interfere with subjective factors and may fail to detect unassignable degrees of balance impairment. Thirdly, tetra-ataxiometry evaluates only static balance. However, in daily life most of our tasks require dynamic balance as well. We also do not know the confounding factors for tetra-ataxiometric evaluation such as, body mass index or age. Therefore, the contribution of such factors to our results is not discussed in this paper.

In conclusion, compared to participants who have low joint mobility scores, participants who have distinctly hypermobile joints have impaired postural stability in the head-extended and head-rotated positions. This increased instability may lead to an increased risk of musculoskeletal injuries. Clinicians and trainers are advised to evaluate joint mobility before prescribing exercises or recommending sports activities.

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