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## Decoding injury risk: Exploring the impact of asymptomatic hypermobility on lower limb injury risk factors in young female volleyball players

Ivana Hanzlíková<sup>a</sup>, Kristýna Klimešová<sup>a</sup>, Michal Lehnert<sup>b</sup>, Lucia Bizovská<sup>c</sup>, David Smékal<sup>a</sup> and Kim Hébert-Losier<sup>d</sup>

<sup>a</sup>Department of Physiotherapy, Faculty of Physical Culture, Palacký University Olomouc, Olomouc, Czech Republic; <sup>b</sup>Department of Sport, Faculty of Physical Culture, Palacký University Olomouc, Olomouc, Czech Republic; <sup>c</sup>Department of Natural Sciences in Kinanthropology, Faculty of Physical Culture, Palacký University Olomouc, Olomouc, Czech Republic; <sup>d</sup>Division of Health, Engineering, Computing and Science, Te Huataki Waiora School of Health, University of Waikato, Tauranga, New Zealand

### ABSTRACT

Generalized hypermobility is associated with higher rates of musculoskeletal injuries, a trend also observed in volleyball. We aimed to investigate how asymptomatic hypermobility affects other suggested lower limb injury risk factors. Fifty female volleyball players (22 hypermobile, 28 non-hypermobile) were assessed using Beighton scores (BS) and lower limb injury risk factors based on the Landing Error Scoring System, single-leg dynamic balance, and Limb Symmetry Index (LSI) for single-leg hop and triple hop for distance. Spearman's correlations assessed relationships between BS and the risk factors, and t-tests or Mann-Whitney U tests compared risk factors between non-hypermobile and asymptomatic hypermobile groups. No significant associations were found between BS and most risk factors, except for a negative correlation with the centre of pressure range of motion in the medio-lateral direction during dynamic balance on the non-dominant leg ( $\rho = -0.332$ ;  $p = 0.015$ ). The only significant group difference was in the LSI for single-leg hop distance, where the hypermobile group showed greater symmetry ( $r = 0.28$ ,  $p = 0.041$ ). The association between BS and dynamic balance was weak, with no clear difference in injury risk factors were observed between groups, suggesting hypermobile players may not need specialized training programs.

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### KEYWORDS

Beighton score; injury risk; movement screen; Landing Error Scoring System; balance; Limb Symmetry Index

## 1. Introduction

Hypermobility refers to a range of joint movement that exceeds normal physiological limits and can be either localized to specific joints or generalized, affecting multiple joints (Castori et al., 2017). Among children and adolescents aged 3–19 years, the prevalence of generalized hypermobility is 34.1%, with higher rates in girls (32.5%) compared to boys (18.1%) (Sobhani-Eraghi et al., 2020).

The classification of hypermobility has long been inconsistent. To address this issue, Castori et al. (2017) proposed a system dividing generalized hypermobility into three distinct groups: syndromes associated with hypermobility, symptomatic hypermobility, and asymptomatic hypermobility. The first group encompasses hereditary connective tissue disorders, such as Ehlers-Danlos Syndrome, Marfan Syndrome, and Loeys-Dietz Syndrome. Symptomatic hypermobility refers to individuals who do not meet the criteria for specific syndromes, but exhibit symptoms due to hypermobility,

such as pain, fatigue, and frequent musculoskeletal trauma. Asymptomatic hypermobility, arguably the most common in the sport environment, is characterized by joint hypermobility without pain or other symptoms. Most studies do not differentiate between these groups, leading to unclear applicability of results across all groups (Pacey et al., 2010; Sundemo et al., 2019).

Hypermobility individuals commonly experience musculoskeletal problems, such as overuse injuries; joint dislocation; ligament, muscle, and meniscus tears; as well as osteoarthritis (Simmonds, 2022). To assess the impact of generalized hypermobility on the incidence, prevalence, and severity of sports-related injuries, Tingle et al. (2018) conducted a systematic review. The review included male and female athletes from various sports, as well as military personnel, aged 6 to 38 years. They found a significant association in multiple studies between hypermobility and an increased lower limb injuries incidence and prevalence, though no significant link was established for upper limb injuries. There were

**CONTACT** Ivana Hanzlíková  [ivana.hanzlikova@upol.cz](mailto:ivana.hanzlikova@upol.cz); [xhanzlikova@gmail.com](mailto:xhanzlikova@gmail.com)  Department of Physiotherapy, Faculty of Physical Culture, Palacký University Olomouc, Třída Míru 117, Olomouc 771 47, Czech Republic

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mixed results regarding the association between generalized hypermobility and injury severity or specific sport types. In contrast to the latter finding, systematic review of Pacey et al. (2010), exploring sport population between 12 to 39 years old, found a significantly increased risk (Odds ratio = 4.69) of knee injuries in hypermobile individuals, but no increased risk for ankle injuries. Sundemo et al. (2019), in a systematic review exploring a population similar to that of previous reviews, reported that generalized hypermobility is a risk factor for unilateral anterior cruciate ligament (ACL) injuries in males, with mixed results for females. A 4.5-year prospective cohort study of female athletes with a mean age of 17.2 years participating in team sports did not find a significantly higher odds ratio of ACL injury in the hypermobile group (Pasanen et al., 2025). In contrast, Zsidai et al. (2023) identified an elevated risk of re-injury or contralateral ACL injury post-surgery in hypermobile patients with a mean age of 23.7 years. Another prospective cohort study of patients aged 16–50 reported that those with generalized joint hypermobility were less likely to return to sport and exhibited less symmetrical knee extension strength two years after ACL reconstruction (Lindskog et al., 2023). Other studies, such as Junge, Larsen et al. (2015) and Nathan et al. (2018), found varied results, and indications that generalized hypermobility may sometimes protect against certain injuries. It appears that more research is needed to explore the effects of generalized hypermobility on sports-related lower limb injuries and their risk factors in greater depth, ideally through prospective studies.

Volleyball is a team, non-contact sport that ranks among the most popular sports globally, especially among female athletes (de Azevedo Sodré Silva et al., 2023; Reeser et al., 2006). It requires players to make quick movements, necessitating good motor and sensory skills to avoid injuries (Bere et al., 2015). Typical volleyball actions, such as jumping, landing, blocking, and hitting the ball, combined with rapid changes in movement place high demands on the musculoskeletal system (Bere et al., 2015). McGuine et al. (2020) studied 2,072 high school female volleyball players and found that over half of acute injuries were due to contact with the ball or teammates, while non-contact injuries mainly resulted from jumping and landing, with others identified as overuse injuries. Kilic et al. (2017) identified the ankle, knee, and shoulder as the most frequently injured areas, with incidence rates from 1.7 to 10.7 injuries per 1,000 hours played. A systematic review by de Azevedo Sodré Silva et al. (2023) on volleyball injuries in youth athletes (aged 12–18) predominantly involved girls, who comprised 91.4% of the 3,698 players studied. This reflects the higher participation of females in volleyball

across most countries. The review found that the most common injuries were to the ankle, distal upper extremities (fingers, wrist, and hand), and knee, with an injury incidence ranging from 1.24 to 5.3 injuries per 1,000 hours played.

Poor balance and asymmetry in jump distance between lower limbs are risk factors associated with a higher incidence of knee and ankle injuries, particularly in female athletes (Collings et al., 2021). A combination of suboptimal scores on the single leg hop test, standing long jump, and poor limb symmetry index has been identified as injury risk factors, specifically in female volleyball players with a mean age of 19 years (Brumitt et al., 2020; Patterson et al., 2021). Additionally, suboptimal biomechanics during vertical jumps have also been recognized as a significant risk factor (Dingenen et al., 2014). Generalized hypermobility may also play a role in volleyball injuries. Sueyoshi et al. (2016) found that high school female volleyball players with a history of ligament injuries had significantly higher Beighton scores (BS), with a mean difference of 1.23, indicating greater hypermobility. Additionally, players with multiple or recurrent ligament injuries had higher BS (mean difference = 1.23) than those with a single injury. However, it is not clear which specific lower limb risk factors are affected by generalized hypermobility. Understanding these associations is crucial for designing effective sports training strategies and developing injury prevention programs tailored to the needs of hypermobile athletes. Therefore, we aimed to explore the association between hypermobility and other suggested lower limb injury risk factors, including the Landing Error Scoring System (LESS), single-leg dynamic balance, and Limb Symmetry Index (LSI) from single-leg hop for distance and single-leg triple hop for distance tests. Additionally, we aimed to compare these lower limb risk factors between asymptomatic hypermobile and non-hypermobile young female volleyball players. We hypothesized that hypermobility would be associated with poorer performance in single-leg dynamic balance and LSI, and that hypermobile players would have worse results in these tests compared to non-hypermobile players.

## 2. Materials and methods

### 2.1. Participants

We determined the necessary sample size to detect a moderate correlation (i.e., 0.40) as described by Akoglu (2018). This calculation was conducted using G\*Power version 3.1.9.7 (Faul et al., 2007), based on standard two-tailed hypothesis testing equations with an 80% power ( $\beta = 0.20$ ) and a 5% significance level ( $\alpha =$

0.05). To identify a moderate correlation, we needed 44 participants.

All female athletes within the target age group from a local volleyball team were invited to participate in the study, as they shared similar training volume and characteristics. Out of 80 potential participants, 56 consented to participate, and 50 were included in the statistical analysis due to missing data or the inability to perform the task correctly. All participants were female volleyball players aged 7 to 15 years from the same club, training 1.5 hours per session, three times per week. Prior to the study, it was ensured that none of the participants had any injuries or pain that would limit their physical activity, and there were no reports of significant injuries or surgeries within the previous three months. Additionally, individuals with diagnosed medical syndromes associated with joint hypermobility (e.g., Ehlers-Danlos syndrome, Marfan syndrome) or symptomatic hypermobility were excluded (Castori et al., 2017). Symptomatic hypermobility was defined as a Beighton score of  $\geq 5$  (Singh et al., 2017) accompanied by either pain in two or more joints, non-specific back pain lasting at least three months, or joint pain in any location lasting more than three months (Grahame et al., 2000).

The Ethics Committee of the Faculty of Physical Culture, Palacký University approved the study protocol (15/2023), which was conducted in compliance with the Declaration of Helsinki. Written informed consent was obtained from all participants' guardians, who were given comprehensive information about the potential risks of the testing procedures such as muscle pain or injury.

## 2.2. Procedure

Measurements were conducted over two consecutive days. On the first day, height, mass, hypermobility, and dynamic balance were assessed. On the second day, following a standardized warm-up (including dynamic stretching, bilateral and unilateral vertical submaximal jumps, horizontal jumps, and three sprints at progressive intensities of 60%, 90%, and 100% of maximum effort), LESS, and horizontal single-leg hops (a single hop and a triple hop to calculate LSI) were performed. Participants wore sports attire and their own sports shoes but were barefoot for the dynamic balance test. At the beginning of each session, participants were divided into groups of three, rotating through each station with the order of stations randomized for each group. Additionally, for each participant, the starting lower limb (dominant and non-dominant) for horizontal hops and dynamic balance testing was randomized. The dominant leg was defined as the leg used to kick a ball.

All assessors were experienced physiotherapists with a minimum of three years of clinical practice and were familiar with the tests. Each test was consistently assessed by the same evaluator to ensure reliability.

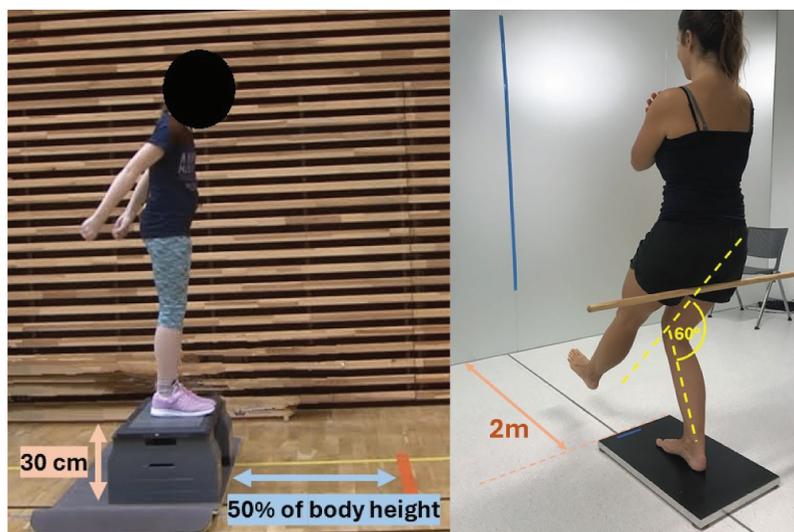
### Beighton score

The BS is a well-established and reliable measure for diagnosing generalized joint hypermobility (Juul-Kristensen et al., 2017; Remvig et al., 2007). An evaluator used standardized protocols and a hand-held goniometer (Smits-Engelsman et al., 2011) for assessment. The evaluation included five components: (1) passive dorsiflexion and hyperextension of the fifth metacarpophalangeal joints beyond  $90^\circ$ , (2) passive opposition of the thumbs to the flexor aspects of the forearms, (3) passive hyperextension of the elbows beyond  $10^\circ$ , (4) passive hyperextension of the knees beyond  $10^\circ$ , and (5) active forward flexion of the trunk with fully extended knees and feet hip-width apart, allowing the palms to rest flat on the floor (Beighton et al., 1973). The first four components can each score up to 2 points, as they are assessed bilaterally, while the last component can score a maximum of 1 point. Therefore, the total BS ranges from 0 to 9 points. Participants were categorized into asymptomatic hypermobile ( $BS \geq 5$ ) and non-hypermobile ( $BS < 5$ ) groups, according to age and sex-specific thresholds of BS (Singh et al., 2017).

### Landing Error Scoring System

The LESS, developed by Padua et al. (2009), is a tool for identifying landing patterns that may increase ACL injury risk, with minimal space, time, and equipment requirements, making it suitable for screening in sports teams. LESS demonstrates good to excellent intrarater, interrater, and intersession reliability, with the validity of individual LESS items related to key ACL injury risk factors ranging from moderate to excellent in the literature (Hanzlíková & Hébert-Losier, 2020b).

The testing required a 30 cm high box and a marked landing zone on the ground (Figure 1). The distance from the box to the landing zone was set to 50% of the participant's height. Two video cameras (SONY HXR-MC2000 and SONY HXR-NX5E, SONY, Japan) with a sampling frequency of 50 Hz were used. The cameras were positioned 1.2 m above the ground and 3 m from the landing zone; one camera was placed in front to capture the frontal plane, and the other on the right side to capture the sagittal plane. The starting position was standing on the box with toes aligned with the edge. Participants were instructed to jump forward using both feet to the landing zone, and then immediately perform a maximal vertical jump. After instructions, participants completed one practice jump. Three



**Figure 1.** Illustration of Landing Error Scoring System (left) and single-leg dynamic balance (right).

measured trials were performed with a 30-second rest between each. Footage of all three jumps was evaluated using the LESS scoring sheet (Padua et al., 2009) through video analysis with Kinovea® (version 0.9.5). For evaluation, the videos were randomly assigned to three raters. An intraclass correlation coefficient ( $ICC_{(3,1)}$ ) was calculated for the first 10 participants to ensure intra-rater reliability, which was 0.86 (95% Confidence intervals [CI] = 0.68–0.95). The average LESS score from the three trials was used for statistical analysis.

### Single-leg dynamic balance

To evaluate dynamic balance, we used a single-leg squat test on a force platform, as described by Culvenor et al. (2016). The Kistler force platform (9286AA, Kistler Group, Winterthur, Switzerland), collecting data at 200 Hz was used and positioned two meters from a wall.

Participants began the test standing barefoot on one leg at the centre of the force platform. The non-tested leg was extended forward, arms crossed on the chest, and gaze fixed on a vertically placed tape on the wall (Figure 1). A bar was positioned behind the participant, aligned with the heels to mark the squat depth. The bar was set to touch the buttocks at 60° knee flexion, which was verified with a goniometer prior to testing.

Participants were instructed to perform five single-leg squats to the specified depth (buttocks touching the bar) in sync with a metronome set at 0.5 Hz, allowing 2 seconds for descent and 2 seconds for ascent per squat. No specific instructions regarding trunk position were provided. One practice trial was conducted before testing. Invalid trials, such as touching the ground with the non-tested leg, moving arms, or sitting on the bar

were repeated. Only one correct trial was included in the analysis.

The centre of pressure (CoP) coordinates in medial-lateral and anterior-posterior directions were low-pass filtered using a 4<sup>th</sup> order bidirectional Butterworth filter with a cut-off frequency of 12 Hz (Culvenor et al., 2016). The average speed and range of CoP movement for trials performed on dominant and non-dominant legs were computed using a custom written Matlab scripts and included in statistical analysis (R2022b, MathWorks, Natick, Ma, USA).

### Limb Symmetry Index for Hops

To calculate the LSI, each participant performed two trials of single-leg hop for distance and single-leg triple hop for distance on both their dominant and non-dominant legs (Sylvester et al., 2024). Participants started each hop standing with the toes of the tested leg behind the start line. For the single-leg hop, participants performed a maximal hop for distance, landing on both feet. In the single-leg triple hop, participants executed three maximal consecutive hops for distance without pausing, landing on both feet after the final hop. Arm movement was unrestricted, allowing participants to use their arms for momentum and balance. Hops were considered faults and repeated if participants moved their feet upon landing, placed their hands on the ground to stabilize themselves, or if the free leg touched the ground before the final landing.

A measuring tape was affixed to the floor, aligned with the take-off line, and a long ruler was used to measure total hopping distances from the heel to the take-off line. The longer of the two measured attempts for each hop type (single or triple) on both the

**Table 1.** Participants characteristics.

	All (n = 50)	Hypermobility <sup>a</sup> (n = 22)	Non-hypermobility <sup>b</sup> (n = 28)
Age (years)	12.3 ± 2.0	11.8 ± 2.2	12.7 ± 1.9
Height (cm)	158.4 ± 12.3	155.2 ± 13.3	160.9 ± 11.2
Weight (kg)	50.2 ± 13.2	47.4 ± 13.5	52.4 ± 12.8
BMI (kg/m <sup>2</sup> )	19.7 ± 3.5	19.3 ± 3.7	20.0 ± 3.4
Body fat (%)	22.3 ± 7.7	21.5 ± 8.4	23.0 ± 7.1
Beighton Score	4 (3)	6 (1)*	2 (1)*

BMI, body mass index; n, number of participants.

Number are presented as mean ± standard deviations or median (interquartile range).

<sup>a</sup>Participants with Beighton score ≥ 5.

<sup>b</sup>Participants with Beighton score < 5.

\*Significant difference between the groups according to Mann-Whitney U

dominant and non-dominant limbs was used to calculate LSI. LSI was calculated as the ratio of the maximum hop length of the dominant limb to the maximum hop length of the non-dominant limb, multiplied by 100 and expressed as a percentage (Zarro et al., 2023). LSI for both single and triple hops was included in the statistical analysis.

### Statistical analyses

The Shapiro-Wilk test was used to assess normality, and Levene's test confirmed homogeneity of variance. Descriptive statistics included mean ± standard deviation or median (interquartile range), depending on data distribution.

Given the ordinal nature of BS, Spearman's correlation coefficient ( $\rho$ ) was used to examine correlations between BS and other suggested risk factors (LESS, single-leg dynamic balance, LSI for hops). Spearman's coefficient was interpreted as follows: 0–0.39 for weak; 0.40–0.69 for moderate; 0.70–0.99 for strong; and 1 for perfect correlation (Akoglu, 2018).

For comparing asymptomatic hypermobile and non-hypermobility groups, an independent two-sample t-test was used for normally distributed

data, and the Mann-Whitney U test was used for non-normally distributed data. Differences in means (for normal data) or Hodges-Lehmann median differences (for non-normal data) with 95% CI were calculated. Effect size (ES) with 95% CI was determined using Hedge's  $g$  for normal data and  $r$  for non-normal data. ES was classified as negligible (0.00–0.19), small (0.20–0.49), medium (0.50–0.79), and large ( $\geq 0.80$ ) (Lakens, 2013). Data were analysed using RStudio® version 2023.09.02 and Microsoft Excel® MS Office 365. Statistical significance was set at  $\alpha = 0.05$ .

### 3. Results

The characteristics of the 50 participants who completed the study are presented in the Table 1. No significant differences were identified in participants' characteristics between groups except for differences in BS between non-hypermobility and asymptomatic hypermobile groups ( $p < 0.001$ , Table 1).

Spearman's correlation analysis did not reveal any significant relationships between BS and suggested risk factors (Table 2), except small negative correlation for the range of motion of the CoP in the medio-lateral direction during dynamic balance on the non-dominant leg ( $\rho = -0.332$ ;  $p = 0.015$ , Table 2). The correlation suggested a decrease in CoP range as BS increased. Additionally, no significant differences were found between the non-hypermobility and asymptomatic hypermobile groups (Table 3), except for the LSI for single-leg hop distance, where the hypermobile group demonstrated greater symmetry (mean difference = 3.5%,  $p = 0.041$ , Table 3).

### 4. Discussion

We aimed to investigate the relationship between hypermobility and various suggested lower limb injury risk factors in young female volleyball players, namely the LESS,

**Table 2.** Spearman's correlation between Beighton scores and risk factors.

Risk factors	Spearman's correlation coefficient	p-value
LESS	0.005	0.972
Dynamic balance dominant leg		
Speed CoP ML	-0.018	0.898
Speed CoP AP	0.118	0.402
ROM CoP ML	0.051	0.717
ROM CoP AP	0.129	0.357
Dynamic balance non-dominant leg		
Speed CoP ML	-0.155	0.267
Speed CoP AP	0.005	0.969
ROM CoP ML	-0.332	<b>0.015</b>
ROM CoP AP	-0.252	0.068
LSI single hop	0.183	0.180
LSI triple hops	0.035	0.799

LESS, Landing Error Scoring System; CoP, centre of pressure; ML, medio-lateral; AP, antero-posterior; ROM, range of motion; LSI, Limb Symmetry Index.

**Table 3.** Comparison of risk factors between non-hypermobile and asymptomatic hypermobile individuals.

Risk factors	Hypermobile <sup>a</sup>	Non-hypermobile <sup>b</sup>	Mean/median difference [95% CI]	p-value	Effect size [95% CI]
LESS (errors)	5.7 ± 1.5	6.1 ± 2.0	−0.4 [−1.5; 0.6]	0.402	−0.23 [−0.79; 0.32]
Dynamic balance dominant leg					
Speed CoP ML (cm/s)	4.9 ± 1.0	4.8 ± 0.9	0.1 [−0.3; 0.7]	0.468	0.20 [−0.34; 0.74]
Speed CoP AP (cm/s)	6.8 ± 1.4	6.3 ± 1.1	0.5 [−0.2; 1.2]	0.159	0.39 [−0.15; 0.93]
ROM CoP ML (cm)	4.1 (0.9)	4.1 (0.7)	0.2 [−0.2; 0.8]	0.449	0.11 [0.01; 0.38]
ROM CoP AP (cm)	7.3 (3.8)	6.5 (1.7)	0.5 [−0.4; 2.0]	0.340	0.13 [0.01; 0.40]
Dynamic balance non-dominant leg					
Speed CoP ML (cm/s)	4.1 (0.9)	4.5 (1.2)	−0.2 [−0.7; 0.2]	0.460	0.10 [0.01; 0.37]
Speed CoP AP (cm/s)	6.4 ± 1.1	6.3 ± 1.3	0.1 [−0.6; 0.8]	0.758	0.08 [−0.45; 0.62]
ROM CoP ML (cm)	3.7 (0.7)	4.0 (0.8)	−0.3 [−0.7; 0.1]	0.071	0.25 [0.02; 0.49]
ROM CoP AP (cm)	6.6 (1.1)	7.1 (1.6)	−0.6 [−1.3; 0.1]	0.121	0.21 [0.01; 0.47]
LSI single hop (%)	100.0 (7.1)	97.2 (8.9)	3.5 [0.1; 7.0]	<b>0.041</b>	0.28 [0.04; 0.52]
LSI triple hops (%)	101.4 (6.1)	98.7 (7.8)	2.4 [−1.0; 5.7]	0.191	0.18 [0.01; 0.44]

LESS, Landing Error Scoring System; CoP, centre of pressure; ML, medio-lateral; AP, antero-posterior; ROM, range of motion; LSI, Limb Symmetry Index; CI, confidence intervals.

<sup>a</sup>Participants with Beighton score ≥ 5.

<sup>b</sup>Participants with Beighton score < 5.

Normally distributed data are presented as mean ± standard deviation, differences in means, p-values from two-sample t-tests, and effect sizes based on Hedge's *g*.

Not-normally distributed data are presented as median (interquartile range), Hodges-Lehmann median differences, p-values from Mann-Whitney U, and *r* effect size.

single-leg dynamic balance, and LSI from single-leg hop for distance and single-leg triple hop for distance. Additionally, we sought to compare these risk factors between asymptomatic hypermobile and non-hypermobile players. Contrary to our hypothesis, no significant associations were found between the BS and the lower limb injury risk factors examined, except for a small negative association with the range of motion of the CoP in the medio-lateral direction during dynamic balance on the non-dominant leg, which suggested better balance in the hypermobile group. Additionally, there were no significant differences in these risk factors between the hypermobile and non-hypermobile groups, except for the LSI for single-leg hop for distance, where the hypermobile group demonstrated greater symmetry. These results suggest that asymptomatic hypermobile young female volleyball players do not show inferior outcomes in the examined lower limb injury risk factors. In fact, the hypermobile group demonstrated better results in some measures. Therefore, based on our findings, asymptomatic hypermobile athletes do not require any additional or specialized training targeting dynamic balance, landing biomechanics, or asymmetries in single-leg jumping beyond what is recommended for the non-hypermobile population.

### LESS

The average LESS score for the entire sample was  $5.9 \pm 1.8$  points, which is comparable to the average score reported in the study by Hanzlíková and Hébert-Losier (2020a) involving active individuals aged 16–41 years ( $5.4 \pm 1.4$  points), as well as by Lehnert et al. (2023) involving elite female handball players with a mean age of 14.3 years ( $6.0 \pm 1.0$  points). This suggests that

our research sample was typical in terms of this evaluated parameter.

Multiple studies have demonstrated that hypermobility can influence the kinetics and kinematics of movement, hence the potential for differences in LESS scores between asymptomatic hypermobile and non-hypermobile participants. Hypermobile individuals have been shown to exhibit postural deviations in the hip and trunk (Booshanam et al., 2011) and altered movement patterns during activities such as stair climbing (Luder et al., 2015), jumping (Alsiri et al., 2020), and walking (Galli et al., 2011; Simonsen et al., 2012). A recent study exploring the relationship between the BS and biomechanical risk factors in adolescent female volleyball players found a significant moderate correlation between peak knee valgus angle and the BS during the double-leg vertical jump, single-leg drop landing, and single-leg squat (Sahin et al., 2024). However, a systematic review found no consistent differences in the gait of hypermobile compared to non-hypermobile individuals (Bates & Alexander, 2015). This lack of consistent findings may be due to the fact that most studies did not differentiate between various hypermobility subgroups or focused specifically on symptomatic hypermobile individuals, potentially overlooking differences between groups.

The LESS was specifically explored in asymptomatic hypermobile ( $n = 26$ ) compared to a non-hypermobile ( $n = 56$ ) populations with average age of  $23.3 \pm 5.8$  years by Hanzlíková and Hébert-Losier (2020a). The investigation focused on whether asymptomatic generalized hypermobility and knee joint hyperextension affect LESS scores, identifying no differences when compared to individuals without hypermobility or knee joint

hyperextension and non-hyperextended, consistent with our study. The authors concluded that this result might be due to the nature of LESS, which assesses only visually apparent gross movement patterns and therefore is not effective in differentiating small changes in kinematics. These authors subsequently assessed differences in biomechanics between non-hypermobility ( $n = 27$ ) and asymptomatic hypermobility individuals ( $n = 15$ ) in another study using three-dimensional analysis of the lower body during a sport-specific unanticipated cutting task (Hanzlíková et al., 2021). The authors identified several biomechanical differences between the groups; however, these differences were not critical biomechanical injury risk factors that could predispose asymptomatic hypermobility individuals to noncontact knee or ACL injuries. Another study that distinguished between asymptomatic and symptomatic hypermobility populations investigated muscle activity during stair climbing in females with a mean age of  $25.3 \pm 5.4$  years (Luder et al., 2015). The findings revealed that the symptomatic, but not asymptomatic, hypermobility individuals had significantly lower peak and mean activation values for the vastus medialis during stair ascent and the semitendinosus during stair descent compared to non-hypermobility individuals. Muscle activity was also explored in asymptomatic hypermobility and non-hypermobility girls 14–15 years old (Nikolajsen et al., 2021). Girls with asymptomatic hypermobility exhibited a significantly increased knee flexion angle during gait. However, there were no significant differences between groups in mean muscle activity or in the co-contraction indexes of the hamstrings-quadriceps, gastrocnemius-quadriceps, and the medial and lateral sides of the knee. On the other hand, a study examining neuromuscular control in a similar population (children aged 10–15 years) during a single-leg hop for distance, without distinguishing between symptomatic and asymptomatic hypermobility, found that the hypermobility group exhibited a gastrocnemius medialis-dominated neuromuscular strategy before landing. This strategy may be attributed to reduced semitendinosus activity both before and after landing, potentially increasing the risk of knee injury (Junge, Wedderkopp, et al., 2015). Collectively, the findings indicate that symptomatology in hypermobility populations is an important differentiating factor in terms of neuromuscular control and biomechanical differences when contrasting to non-hypermobility individuals.

### *Single-leg dynamic balance*

No significant differences were shown between non-hypermobility and asymptomatic hypermobility groups in

terms of single-leg dynamic balance measures. However, a significant negative association was found between the range of motion of the CoP in the medio-lateral direction during dynamic balance on the non-dominant leg and BS ( $\rho = -0.332$ ), indicating reduced shifts of the CoP from side to side, and therefore better balance, in individuals with greater hypermobility. Improved medio-lateral postural control may reduce the risk of lateral ankle injury and instability (McKeon & Hertel, 2008). However, it is important to note that the sample size of our study was calculated to detect correlations of 0.40 and higher, so this finding should be interpreted with caution, especially in light of the small 0.3 cm difference observed between groups in this measure.

Most studies assessing dynamic balance have employed the Y-Balance Test, although its predictive value for injury has been questioned (Plisky et al., 2021), leading to recommendations for using force plates for more accurate balance assessment (McKeon & Hertel, 2008). A study involving 588 participants (mean age:  $7.97 \pm 1.3$  years) found that hypermobility children had a shorter reach distance in the posteromedial and posterolateral directions during Y-Balance Test compared to non-hypermobility children (Ituen et al., 2024). Conversely, a study by Spor et al. (2019) that also compare the Y-Balance Test measures between hypermobility boys and non-hypermobility boys aged 11–12 years found no significant differences between groups. However, neither of these studies specifically differentiated between symptomatic and asymptomatic hypermobility. Selmani et al. (2017) focused on symptomatic hypermobility individuals assessing both dynamic balance using the tandem walk test and static balance. Their findings showed significantly poorer performance in both parameters for the symptomatic hypermobility group, again highlighting that symptomatology is an important consideration.

### *Limb Symmetry Index for Hops*

The LSI is commonly used to assess readiness for return to sports following injury (Myer et al., 2006). A meta-analysis has also identified that asymmetries greater than 10% in single-leg hop distance may be a risk factor in female athletes for ankle injuries, which are prevalent in volleyball (Collings et al., 2021). Furthermore, when the LSI was combined with scores from the standing long jump and single-leg hop, female volleyball players who scored poorly on these tests were found to be four times more likely to experience non-contact lower limb injuries and six times more likely to sustain foot and ankle injuries (Brumitt et al., 2020).

This study found a significant difference in LSI for single-leg hop distance, with asymptomatic hypermobile participants exhibiting significantly better symmetry between their dominant and non-dominant legs compared to non-hypermobile participants. The median difference between the groups was 3.5%, which is below the 10% asymmetry threshold associated with an increased risk of injury (Collings et al., 2021). Additionally, the LSI values for single-leg hop distance ranged from 85.3% to 153.5%, reflecting considerable variability among participants. No significant differences were observed in LSI for single-leg triple hops, and there was no significant correlation between BS and LSI for either type of hops. Thus, the observed differences between groups are unlikely to meaningfully impact the risk of injury in the asymptomatic hypermobile population we examined.

To our knowledge, no study has compared the LSI for hops between hypermobile and non-hypermobile populations. Schmidt et al. (2017) investigated single-leg hops (both single and triple) in adolescents with generalized hypermobility, but did not compare LSI. Instead, they compared the average and maximum jump distances between hypermobile individuals and a non-hypermobile control group. Their results showed no significant differences between the groups for either single or triple hops.

### **Symptomatic and asymptomatic hypermobility**

As mentioned, studies examining asymptomatic hypermobile populations have yielded different results compared to those focusing on symptomatic individuals or studies that did not distinguish between hypermobility groups (Hanzlíková & Hébert-Losier, 2020a; Hanzlíková et al., 2021; Junge, Wedderkopp, et al., 2015; Luder et al., 2015; Nikolajsen et al., 2021). Additionally, research on corticospinal excitability has shown greater excitability in symptomatic hypermobile individuals compared to asymptomatic ones, possibly indicating central nervous system adaptations to compensate for reduced proprioception (Long et al., 2022). Another study found that children with symptomatic hypermobility exhibited significantly greater ranges of motion, increased skin extensibility, lower diastolic blood pressure, and higher levels of degradation products in urine compare to asymptomatic ones (Engelbert et al., 2003). These findings suggest that symptomatic hypermobile individuals may experience more pronounced effects of hypermobility than asymptomatic individuals, leading to different outcomes.

Since hypermobility is typically a genetic disorder, individual adaptations during development can vary,

resulting in different consequences and impairments. For example, one study found that children with joint hypermobility may experience delayed motor development in early childhood, although most catch up with their peers by the age of two (Jaffe et al., 1988). Asymptomatic hypermobile individuals may adapt better than symptomatic ones, leading to varying study results. Furthermore, asymptomatic individuals do not experience additional symptoms (e.g., pain) that could influence movement and injury risk. Therefore, it is crucial to consider the subgroup of hypermobility in examining injury risk factors and planning preventative programmes. Since most injuries occur toward the end of a match when muscles are fatigued (Hawkins et al., 2001; Kilic et al., 2017), assessing injury risk factors in hypermobile groups after muscle fatigue could provide valuable insights and lead to better recommendations and interventions for physically active hypermobile populations.

### **Limitation**

The relatively small sample size limited our ability to detect correlations weaker than moderate. A larger cohort would be necessary to identify these potential relationships, which may influence injury risk within the asymptomatic hypermobile population but are not anticipated to be the primary determinants of injury. Furthermore, the findings cannot be generalized to other subgroups of hypermobility, male athletes, or individuals in different sports. Therefore, further research is essential to investigate these associations in a broader population.

### **5. Conclusion**

The analysis found a small negative correlation between the BS and one measure of dynamic balance, although the meaningfulness of the association is questioned. Additionally, the asymptomatic hypermobile group performed better than the non-hypermobile group on the LSI for the single hop test. However, the differences observed were again small and not clinically meaningful. Consequently, the asymptomatic hypermobile population tested in our study appears to have similar risk factors related to landing movement patterns, balance, and symmetry in single-leg hops compared to the non-hypermobile population. These findings suggest that, in the absence of symptoms, hypermobility alone may not necessitate tailored injury prevention strategies. However, further research is necessary to explore differences in overall injury risks and other specific risk factors

between hypermobile and non-hypermobile groups, particular among symptomatic hypermobile individuals.

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### ORCID

Ivana Hanzlíková  <http://orcid.org/0000-0002-2259-9312>

### Data availability statement

The dataset is available in Zenodo data repository: DOI: 10.5281/zenodo.14922378.

### Human ethics and consent to participate declarations

The study protocol was approved Ethics Committee of the Faculty of Physical Culture, Palacký University (reference number: 15/2023) and adhered to the Declaration of Helsinki. Written informed consent was obtained from all participants' guardians.

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