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Original article

# Does asymptomatic generalized joint hypermobility influence musculotendinous extensibility and knee joint proprioception?

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## Abstract

**Background:** It is unclear whether generalized joint hypermobility (GJH) influences the musculotendinous unit (MTU) extensibility or proprioception of the knee joint in individuals with asymptomatic GJH.

**Objectives:** This study aimed to compare the quadriceps and hamstring MTU length as well as knee joint force sense (FS) and joint position sense (JPS) between individuals with asymptomatic GJH and non-GJH controls.

**Methods:** Thirty-two female subjects were recruited, with 16 subjects in the GJH and non-GJH groups. The angles measured from modified prone knee bend (mPKB) and straight leg raising (SLR) tests were used to identify the quadriceps and hamstrings MTU extensibility using photographic-based angle measurements. The FS of the quadriceps and hamstrings and the JPS of the knee joint were assessed via ipsilateral angle and force-matching tasks, respectively. The results from the GJH and non-GJH groups were compared using unpaired $t$ - tests or chi-square tests based on the distribution of the data.

**Results:** The results indicated that the angles measured by the mPKB and SLR tests were not significantly different between the two groups. Furthermore, neither FS nor JPS differed between the GJH group and their peers.

**Conclusion:** The asymptomatic GJH individuals did not show signs of hyperextensibility of the quadriceps or hamstring muscles. Moreover, the ability to perceive muscle force and the joint position of the knee joint were well preserved.

**Keywords:** Generalized joint hypermobility, hamstrings, quadriceps, knee joint, proprioception.

Joint hypermobility (JH) is a broad term that describes the ability of the joint to be actively or passively moved beyond its physiological limit. JH has been linked to abnormalities of the genes responsible for collagen production, resulting in decreased stiffness of tendons, ligaments, and joint capsules. (1) When JH is observed at four or more joints, this is defined as generalized joint hypermobility (GJH), a condition that can be reliably assessed by the Beighton score. (2 - 4)

Previous studies have reported a high prevalence of knee joint pain or injury among GJH individuals. A hyperextension of ten degrees or higher as measured by the Beighton score (5) emphasizes a serious biomechanical alteration of the joint and the viscoelastic properties of the surrounding tissues. This extreme joint range of motion (ROM), in conjunction with excessive joint instability, can affect the load distribution and cause unwanted mechanical force. This not only increases joint stress but can also lead to ligament and soft tissue injuries, overuse injuries, and predispose affected persons to osteoarthritis from years of excessive joint motion. (6, 7) A previous study reported a greater degree of anterior tibial translation in GJH individuals with knee hyperextension (GJHk) who experienced knee pain. (8) In addition, GJH can alter the mechanical properties of collagen tissues; this may interfere with the viscoelastic property of the musculotendinous unit (MTU), thereby affecting the quality of force production (9) and interfering with

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joint proprioception. [10, 11] It has also been reported that pain is often more severe and lasts longer in these individuals. Therefore, individuals with GJHk have reported a higher incidence of knee pain and reduced knee-related performance in daily activities compared to those without GJH. [7, 12, 13]

The viscoelastic properties of collagen in GJH individuals could affect the extensibility of the MTU. Nonetheless, previous studies have reported conflicting results. Jensen BR. and colleagues compared the electromechanical delay (EMD), an indirect method of measuring MTU stiffness, of the hamstring muscle in individuals with GJH to that of the healthy non-GJH controls and observed no significant difference. [14] Magnusson and co-workers reported that the hamstring muscle stiffness of individuals with benign joint hypermobility syndrome (BJHS) did not differ from that of healthy persons, despite the former having a greater range of knee extension. [15] In contrast, some researchers have reported lesser stiffness of the Achilles tendon along with a greater range of ankle dorsiflexion in other, more severe hypermobile spectrum disorders (HSDs). [16, 17] As MTU stiffness is associated with muscle extensibility [18], measuring muscle extensibility may be an alternative explanation of the MTU characteristics.

In addition to the modification of the MTU, the proprioceptive acuity of the knee joint is altered in individuals with JH. [10, 19 - 21] Proprioceptors require mechanical deformation to signal information regarding the joint position, movement, sensing of heaviness, sensing of effort, and sensing of muscular force (or force sense, FS). [22] Researchers have hypothesized that the number of activated mechanoreceptors in low-stiffness tissue would be decreased. Thus, when a small motion occurs, soft tissue elongation and tension are diminished, resulting in lowered perception and detection by the joint receptors. [21, 23]

Joint position sense (JPS) and movement sense are often carried out to evaluate knee joint proprioception in JH individuals. [10, 19, 21, 23] However, evaluation of FS in hypermobile individuals has not been performed. Considering the extreme knee extension range of the GJHk individuals, the hamstring MTU is considerably stretched, especially in a weight-bearing position. This may alter the Golgi tendon organs (GTOs) that are embedded in the musculotendinous junction. The function of the GTOs is to detect changes in muscle tension and hence muscle force. [22] If this is the case, the FS may be altered.

Even though there have been several studies investigating knee joint proprioceptive acuity in individuals with JH, studies concerning knee joint proprioception in individuals with asymptomatic GJHk are relatively rare. As the clinical presentation of hypermobility varies greatly [1], it may be important to investigate the proprioceptive acuity in conjunction with MTU extensibility in individuals with asymptomatic GJHk. Hence, the aims of this study were to 1) compare quadriceps and hamstring muscle extensibility, and 2) compare force sense and JPS between individuals with asymptomatic GJHk and non-GJH controls. We hypothesized that the quadriceps and hamstring MTU extensibility would be greater in individuals with GJHk, whereas the proprioceptive acuity would be lower.

## Materials and methods

### *Subjects*

The study was designed as a matched-pair comparison between individuals with asymptomatic GJH and non-GJH in terms of age (± 1 year), gender, and physical activity (PA) level. All subjects were screened initially using a questionnaire. Subjects were included if they had no pain in their lower back or lower limb joints, had no history of back or lower limb injuries, and had not had surgery on the leg within the previous 12 months. The subjects were assessed for GJH according to the Beighton scoring system. [24] Those with a Beighton score ≥ 4/9 with both knees hyperextended more than 10° were classified as asymptomatic GJHk. Those with a score ≤ 3/9 and no knee hyperextension (knee extension did not exceed 0 degrees) were classified as non-GJH.

As there was no known previous research on FS of the knee joint in individuals with GJH, the sample size was calculated based on Scheper and associates' study [25] using the G*Power program. The total muscle strength index and its standard deviation (SD) were used. Twenty-six people were identified to be sufficient for 80.0% power, and a 20.0% dropout rate was established in case subjects could not finish the protocol. Therefore, a total of 32 subjects qualified for this study.

All recruited subjects were females; 16 were categorized as asymptomatic GJHk and 16 as non-GJH. During the screening session, the subjects' age, weight, height, knee extension angles, and PA level were recorded. The knee extension angle was measured while the subjects maximally extended their knees while in a standing position using a standard goniometer. The PA was then assessed with the Baecke questionnaire of habitual physical activity. [26] The study has been approved by the research ethics review committee for research involving human research subjects, Group I, Chulalongkorn University (COA no. 084/2021). All subjects gave informed consent prior to data collection.

***Instruments and procedures***

On the date of data collection, the dominant leg of the subject was first identified by asking the subjects to 1) kick a ball to a target placed three meters away; 2) pick up a marker pen from the floor; and 3) draw a figure of eight with one foot. The leg used to execute at least two of the three tasks was identified as the dominant leg. All outcomes were measured on the dominant leg. The order of data collection was as described below.

***Musculotendinous extensibility***

The MTU extensibility was measured by an experienced researcher using a photographic-based angle measurement. Anatomical references were located and marked with colored stickers. The photos of the modified prone knee bend (mPKB) and straight leg raising (SLR) tests were then taken with a digital camera (Sony alpha-6000, Tokyo, Japan) with the highest resolution of 24.3 megapixels. The recommendations for the camera setup by Dunlevy C. and colleagues were followed. [27] One photograph for each test was taken, and the joint angle measurements were performed using the angle tool in the ImageJ software (ImageJ, National Institutes of Health, USA). [28]

The quadriceps MTU extensibility was evaluated by mPKB. The subjects were set in a prone position, and the knee of the dominant leg was fully flexed, while the foot of the non-dominant leg was placed on the floor. [29] Then, the researcher identified and placed colored stickers on the skin over the anatomical landmarks, including the greater trochanter, lateral epicondyle of the femur, and lateral malleolus. The maximum knee flexion angle was used as representative of the quadriceps MTU extensibility.

The hamstring MTU extensibility of the subjects was measured with the SLR test. Subjects were placed in a supine position, and the researcher lifted the straightened leg until the subject reported maximum stretch on the back of the thigh while carefully observing the subject for pelvic movement. The landmarks for measurement of hamstring MTU extensibility included the lateral epicondyle of the femur, the greater trochanter, and the imagery spot parallel to the plinth level. [29] The maximum hip flexion angle was used as representative of the hamstring MTU extensibility.

***Joint position sense (JPS)***

To avoid muscle fatigue, JPS was measured before FS. A Penny and Giles Biometrics® (P and GB) twin-axis electrogoniometer (SG150, Biometrics Ltd., Blackwood, Gwent, UK) was used to quantify knee joint angles for JPS testing. Before each data collection session, the zero setting was calibrated by comparing the read-out angle on the DataLOG with the standard goniometer. Afterward, the electrogoniometer was placed along the lateral side of the tested knee using double-sided tape. The fixed end-box was placed along the longitudinal line of the thigh between the greater trochanter and the lateral epicondyle of the femur. The telescopic end-box was placed along the longitudinal line of the lower leg between the head of the fibula and the lateral malleolus. An SG150 was connected to the DataLOG for real-time data display. The sampling frequency was set to 1,000 Hz. The JPS was tested with an ipsilateral limb repositioning task performed from a single-leg standing position. Subjects were asked to stand on their dominant leg with their hands lightly touching the back of the chair to prevent them from falling. With their eyes closed, subjects were asked to bend their knees down to one of the reference angles and were encouraged to remember the position of the knee joint while holding that position for four seconds, then return to their initial starting position. The research assistant, a physical therapist who had 10 years of experience, asked the subjects to actively replicate the reference knee angle. Once the reference angle was determined, the research assistant noted the repositioned angle shown on the DataLOG. The tested angles included 15°, 30°, and 60° of knee flexion. The order of the tested angles was randomly chosen by drawing lots. Subjects were allowed to rest for at least two minutes between each test angle or until they had no fatigue.

***Force sense (FS)***

The FS was assessed using a custom-made force sensor attached to the knee attachment of the Biodex chair. The load cell (YZC-1B, Guangdong, China) and customized software developed on the Visual Studio platform (Microsoft.NET development series) were used to collect force sense data from the knee flexor and knee extensor muscles. The sampling frequency of the force sensor was set to 1,000 Hz. The zero setting of the force sensor was carried out before data collection to cancel out the limb weight. The processed force data were presented on the monitor, providing real-time feedback to the subjects.

Before starting the actual tests, the reliability of the load cell was tested using sets of standard weights from 1 to 10 kg with a 1 kg increment. Additional weights of 1.5 and 2.5 kg, were also included to test for load cell sensitivity in the low load range. The force sensor proved to be highly reliable (ICC3, 3 = 1, $P < 0.001$).

The FS of both quadriceps and hamstring muscles were tested at 15° of knee flexion. Subjects sat comfortably on the Biodex chair with their chest, pelvis, and tested thigh securely strapped to prevent compensatory movement during testing. The force sensor was placed on the anterior or posterior aspect of the tibia, 2 cm above the lateral malleolus, to measure the FS of the quadriceps or hamstring muscles, respectively. Then, three maximum voluntary isometric contractions (MVICs) of the corresponding muscle were measured by exerting and holding maximum effort against the load cell for five seconds. The highest force measured among the three trials was designated as the MVIC. The reference value of 10.0%, 30.0%, or 50.0% of the MVIC was set. Subjects were instructed to obtain the target force using visual feedback from the computer screen. They were then asked to maintain the contraction while remembering the target force for five seconds, and then relax. The subjects were then asked to reproduce the target force with the same leg while blindfolded. Once the reference force was deemed achieved, the five-second reproduction phase was recorded. Three trials were conducted for each force level, with 20 seconds of rest between trials. The rest duration between each force level was five minutes or until subjects reported no fatigue. The average value of each 5-second trial was used to calculate the perception errors of the FS.

***Data analysis***

Both JPS and FS were tested for their acuity using three types of error measurements: absolute error, relative error, and variable error. The absolute error and relative error were calculated as (reposition angle - reference angle). While the absolute error reflected the magnitude of error without the directional bias, the relative error represented the directional bias in the data. If the relative error was positive, this indicated that the subject overestimated the reference angle. Conversely, if the result was negative, this indicated that the subject underestimated the reference angle. Lastly, the variable error reflected the reliability of the response, which represented the consistency of subjects' responses to the test angle. This was determined as the standard deviation (SD) from the mean of three relative errors. [30]

***Statistical analysis***

Statistical analysis was performed using SPSS version 28 for Windows (SPSS Inc., Chicago, IL, USA). The data were expressed as mean (SD) or median (interquartile range, IQR). The Shapiro-Wilk test revealed that the data distribution was a mix of normal and non-normal distributions. The unpaired *t* - tests and Mann-Whitney U tests were used when appropriate to compare the differences between groups. The level of significance was set at $P < 0.05$.

## Results

Thirty-two subjects were recruited for this study, with sixteen in each group. All subjects were female. The age of the subjects ranged between 19 and 25 years. The mean Beighton scores were 5.5 (1.4) and 1.1 (1.2) for the GJHk and non-GJH groups, respectively. Other subjects' characteristics showed no statistically significant difference between groups, indicating homogenous groups in terms of age, gender, weight, height, body mass index (BMI), and level of physical activity **(Table 1).**

There were no differences in quadriceps or hamstring extensibility between groups **(Table 1)**. Furthermore, neither the FS of the quadriceps and hamstring muscles nor the JPS were significantly different between groups **(Tables 2 - 4).**

**Table 1.** Characteristics of GJH and non-GJH subjects.

| Group | GJHk (n = 16) | non-GJH (n = 16) | *P* - value |
|---|---|---|---|
| Age (year) | 20.4 (1.4) | 20.5 (1.7) | 0.897 |
| Weight (kg) | 50.9 (4.3) | 50.7 (5.9) | 0.886 |
| Height (m) | 1.6 (0.1) | 1.6 (0.1) | 0.119 |
| BMI (kg/m$^2$) | 19.6 (1.9) | 20.2 (1.7) | 0.337 |
| Beighton | 5.5 (1.4) | 1.1 (1.2) | < 0.001* |
| **Knee extension angle (°)** | | | |
| Right knee | - 14.1 (2.4) | 1.6 (1.8) | < 0.001* |
| Left knee | - 15.0 (2.8) | 1.7 (1.8) | < 0.001* |
| PA score | 7.6 (0.8) | 7.4 (0.7) | 0.694 |
| PA level | 2.3 (0.5) | 2.3 (0.5) | 1.000 |
| Muscle extensibility | | | |
| SLR[a] (°) | 65.5 (11.6) | 68.7 (8.9) | 0.265 |
| mPKB[b] (°) | 142.0 (16.1) | 140.3 (9.6) | 0.724 |

GJHk, Generalized joint hypermobility with knee hyperextension; non-GJH, non-generalized joint hypermobility; BMI, Body mass index; PA, Physical activity; SLR, Straight leg raising; mPKB, Modified prone knee bend; [a]hamstring muscle extensibility; [b]quadriceps muscle extensibility.
Minus value indicates hyperextension.

**Table 2.** Force sense errors of hamstrings muscle.

| Force sense | GJHk (n = 16) | non-GJH (n = 16) | *P* - value |
|---|---|---|---|
| HAM_MVIC (N)[b] | 131.7 (34.9) | 147.1 (35.7) | 0.225 |
| **10.0% MVIC** | | | |
| Absolute error [a] | 2.8 (3.4) | 4.0 (3.4) | 0.270 |
| Relative error[b] | 0.8 (3.4) | 2.3 (5.0) | 0.332 |
| Variable error[a] | 2.0 (1.4) | 2.7 (2.3) | 0.254 |
| **30.0% MVIC** | | | |
| Absolute error [a] | 4.1 (5.8) | 4.0 (6.0) | 0.838 |
| Relative error[b] | - 1.1 (8.2) | 1.5 (7.2) | 0.362 |
| Variable error[a] | 3.1 (2.7) | 3.8 (2.6) | 0.504 |
| **50.0% MVIC** | | | |
| Absolute error[b] | 7.8 (6.2) | 9.9 (4.8) | 0.284 |
| Relative error[b] | - 6.3 (7.2) | - 3.4 (10.2) | 0.349 |
| Variable error[a] | 4.3 (2.8) | 5.6 (3.6) | 0.254 |

[a]The results from Mann-Whitney U test are shown as median (IQR).
[b]The results from unpaired *t* - test are shown as mean (SD).
HAM_MVIC, Hamstring maximum voluntary isometric contraction.

**Table 3.** Force sense errors of quadriceps muscle (results from 5 seconds).

| Force sense | GJHk (n = 16) | non-GJH (n = 16) | *P* - value |
|---|---|---|---|
| QUAD_MVIC (N)[b] | 135.1 (37.2) | 142.5 (49.0) | 0.635 |
| **10.0% MVIC** | | | |
| Absolute error[a] | 5.2 (6.0) | 5.4 (6.5) | 0.897 |
| Relative error[b] | 5.1 (5.6) | 6.5 (7.2) | 0.550 |
| Variable error[a] | 3.1 (1.8) | 2.6 (2.4) | 0.521 |
| **30.0% MVIC** | | | |
| Absolute error[a] | 11.2 (11.6) | 7.3 (8.8) | 0.102 |
| Relative error[b] | 8.2 (11.6) | 5.3 (7.7) | 0.411 |
| Variable error[a] | 5.7 (3.1) | 4.3 (2.0) | 0.128 |
| **50.0% MVIC** | | | |
| Absolute error[a] | 7.4 (12.5) | 8.0 (15.8) | 0.809 |
| Relative error[a] | 4.2 (16.1) | 4.4 (20.6) | 0.724 |
| Variable error[a] | 6.1 (5.4) | 5.0 (3.0) | 0.445 |

[a]The results from Mann-Whitney U test are shown as median (IQR).
[b]The results from unpaired *t* - test are shown as mean (SD).
QUAD_MVIC, Quadricep maximum voluntary isometric contraction.

**Table 4.** Joint position sense errors.

| Test angles | GJHk (n = 16) | non-GJH (n = 16) | *P* - value |
|---|---|---|---|
| **Knee flexion 15°** | | | |
| Absolute error[a] | 2.3 (2.3) | 2.7 (2.3) | 0.539 |
| Relative error[b] | 1.3 (3.0) | 2.4 (2.9) | 0.281 |
| Variable error[a] | 1.1 (1.1) | 0.8 (0.5) | 0.341 |
| **Knee flexion 30°** | | | |
| Absolute error[a] | 2.0 (4.2) | 2.8 (3.4) | 0.564 |
| Relative error[b] | 1.2 (4.6) | 2.1 (3.9) | 0.522 |
| Variable error[a] | 0.9 (0.6) | 0.9 (1.2) | 0.642 |
| **Knee flexion 60°** | | | |
| Absolute error[a] | 3.5 (1.4) | 3.8 (2.5) | 0.381 |
| Relative error[b] | 0.4 (3.3) | - 0.3 (3.8) | 0.586 |
| Variable error[a] | 3.4 (1.4) | 2.7 (1.4) | 0.616 |

[a]The results from Mann-Whitney U test are shown as median (IQR).
[b]The results from unpaired *t* - test are shown as mean (SD).
GJHk, Generalized joint hypermobility with knee hyperextension.

## Discussion

This study compared the MTU extensibility and proprioceptive acuity between asymptomatic GJHk and non-GJH individuals. The main findings of the study showed that the quadriceps and hamstrings MTU extensibility as well as the proprioceptive acuity were comparable between the two groups.

It is commonly believed that individuals with JH would have altered mechanical properties of their MTU, ligaments, and joint capsules. (31) However, the results of this study did not support this hypothesis. Although the recruited subjects in the GJHk group had much greater knee hyperextension (> 10°) than the non-GJH group, both quadriceps and hamstring muscle extensibility were comparable between groups. Our results were in accordance with those of Ewertowska P. and co-workers who also reported no difference in quadriceps or hamstring muscle length between GJH and non-GJH individuals. (32)

The insignificant difference in muscle extensibility could be due to the age of the subjects. Based on Jensen BR. and colleagues' study, the EMD of the quadriceps was significantly longer in children with GJH than non-GJH children, but no difference was found in adulthood. (14) As MTU stiffness is associated with muscle extensibility (18), the GJH subjects may have reduced the extensibility of both quadriceps and hamstring MTUs, resulting in comparable quadriceps and hamstring MTU extensibility. Alternatively, asymptomatic GJH may not produce alteration of the MTU in the first place.

As proprioceptors usually require mechanical deformation to function, researchers have suggested that their responsiveness would be reduced in lax soft tissue. (10, 33) It has been hypothesized that the FS can be disrupted due to an alteration of the tendon surrounding the knee joint, and hence the GTO function. However, as neither the quadriceps nor the hamstring extensibility differed between asymptomatic GJHk and non-GJH adults, we assumed that the stiffness of these muscles did not differ between the two groups. (14) This allowed the GTO to continue to function as normal and correctly detect muscle force.

Furthermore, the movement detection was better near the end range of knee extension. (10) The FS measurement was conducted at a nearly full knee extension position that placed the MTU tension to its maximum, especially in the hamstring muscle. Given that the two groups had comparable MTUs and presumably comparable MTU stiffness, the muscle force perceived by the GJHk subjects was not disturbed by the presence of hypermobility.

In contrast to previous studies that have assessed knee JPS in a non-weight-bearing position (19, 20, 23), the current study did not find knee JPS impairment in a weight-bearing position. The weight-bearing position is a valid assessment of the knee JPS. (33) Although it has been suggested that a larger amount of proprioceptive signals from outside the tested joint may have been produced (34, 35), the weight-bearing position is more similar to functional activities. Therefore, the GJHk subjects may have correctly determined their knee joint position by using a combination of proprioceptive inputs from outside the knee joint. Additionally, the recruited subjects were free of injury in the lower back and all of their lower limb joints, factors that could hinder their joint perception. All subjects were also living an active lifestyle. This could indicate that there was no damage to any of the proprioceptors.

The strengths of this study are threefold. The use of the matched-pair approach in recruiting subjects provides researchers with the confidence that the results will reflect genuine differences between asymptomatic GJHk and non-GJH individuals. Moreover, the results of the study provide missing information regarding the proprioceptive capability of individuals with asymptomatic GJHk. By using highly reliable force sensors for testing FS and testing knee JPS in a weight-bearing position (34), the results of the study provide accurate information regarding knee joint proprioception of individuals with asymptomatic GJHk.

This study was conducted with some limitations. First, the number of subjects in each group was low. Further study with a larger population may help clarify the proprioceptive capability of individuals with asymptomatic GJHk. Second, the current study recruited individuals with asymptomatic GJHk, a sample that may have a different clinical presentation from those who have pain. Lastly, all subjects were female, a factor that has been found to influence proprioceptive capability compared to their male counterparts. (36) Hence, the results of this study should be used cautiously due to their limited generalizability.

## Conclusion

The results of the present study suggest that the asymptomatic GJHk individuals showed no adverse effects on quadriceps or hamstring muscle extensibility, nor did their condition affect the proprioceptive acuity, both JPS and FS, of the knee joint. This was indicated by the comparable muscle extensibility and non-significant differences in the proprioceptive error scores.

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### Conflict of interest statement

Each of the authors has completed an ICMJE disclosure form. None of the authors declare any potential or actual relationship, activity, or interest related to the content of this article.

### Data sharing statement

The data sets generated or analyzed during the present study are available from the corresponding author on reasonable request.

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