Reliability and Precision of Hip Proprioception Methods in Healthy Individuals

Anne Benjaminse, MS, PT, Timothy C. Sell, PhD, PT, John P. Abt, PhD, ATC, Anthony J. House, MS, ATC, and Scott M. Lephart, PhD, ATC

Objective: The goal of this study was to establish the intrasession and intersession reliability and precision of threshold to detect passive motion (TTDPM), force sense (FS), and active joint position sense (JPS) tests for the hip in healthy individuals.

Design: Descriptive laboratory study.

Setting: Research laboratory.

Participants: Data were collected on 20 subjects between the ages of 18 and 30 years. They were physically active and had no history of major lower extremity injury or surgery or hip injuries.

Interventions: Threshold to detect passive motion, FS, and active JPS were measured using a Biodex System 3 and a Vicon Motion Analysis System.

Main Outcome Measures: Error scores were calculated as the absolute difference between the reference and reproduction values. Intraclass correlation (ICC) and standard error of measurement (SEM) were used to assess intrasession and intersession reliability and precision.

Results: Adduction showed good reliability for JPS, with an intersession ICC (SEM) of 0.753 (0.248 degrees). For TTDPM, abduction showed an intrasession ICC (SEM) of 0.825 (0.256 degrees) and adduction had an intrasession ICC (SEM) of 0.765 (0.266 degrees). The intersession ICCs (SEM) were as follows: flexion 0.810 (0.143 degrees), extension 0.777 (0.195 degrees), abduction 0.906 (0.176 degrees), and adduction 0.893 (0.144 degrees). Flexion showed a good intersession ICC for FS: 0.764 (0.932 Nm).

Conclusions: Results indicate that a reliable and precise method of measuring hip TTDPM has been established. Further investigation is necessary to develop reliable and precise measurement methods for FS and active JPS of the hip and to identify if TTDPM is related to hip kinematics, hip kinetics, and muscle activation about the hip during functional tasks.

Key Words: ACL, hip, neuromuscular control, precision, proprioception, reliability

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INTRODUCTION

Proprioceptive information from joint, ligamentous, and muscle mechanoreceptors and accompanying neuromuscular control mechanisms play an integral role in the process of maintaining functional joint stability.[1] Compromised function of the trunk and hip stabilizers, as they relate to core neuromuscular control, may underlie the mechanisms of increased anterior cruciate ligament (ACL) injury risk in female athletes.[2–5] Hip coordination has been related to ACL injury along the lower extremity kinetic chain.

Lesser activation of the proximal hip-stabilizing muscles may contribute to excessive valgus motion (derived from femoral internal rotation and adduction).[6–8] This position has been observed in female athletes during landing and is frequently associated with noncontact ACL injuries.[9–11] Proprioceptive deficits of the hip and core may diminish neuromuscular control of the lower extremity, resulting in greater valgus angulation and increased strain on the ligaments of the knee.[2,5,12,13]

Recent focus on functional joint stability of the hip in relation to the knee leads to a relatively new research area. There is limited research examining proprioception of the hip, with a majority focusing on proprioception in the elderly after hip fracture or total hip replacement.[14–17] None of these studies investigated the reliability of measuring hip proprioception. The purpose of this study was therefore to establish the intersession and intrasession reliability and precision of threshold to detect passive motion (TTDPM), force sense (FS), and active joint position sense (JPS) of the hip in healthy individuals.

METHODS

Subjects

Twenty (10 males and 10 females) healthy and physically active subjects between the ages of 18 to 30 years participated in this study (Table 1). Physically active was defined as subjects performing exercise for a minimum of 30 minutes a day, 3 times a week. Activity level was scored based on the Tegner Activity Level Scale.[18,19] Written informed consent according to the University's Institutional Review Board was obtained from the subjects before participation in the study.

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From the Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, Pennsylvania.

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Reprints: Timothy C. Sell, PhD, PT, Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, School of Health and Rehabilitation Sciences, University of Pittsburgh, 3830 South Water St, Pittsburgh, PA 15203 (e-mail: tcs15@pitt.edu).

TABLE 1. Subject Demographics

	Mean (SD)
Age, y	23.70 (3.05)
Height, cm	168.98 (8.79)
Mass, kg	69.39 (10.79)
Tegner Activity Level Scale	6.10 (1.33)

Procedures

Data Collection

All subjects attended 2 testing sessions, 1 week apart. Threshold to detect passive motion and FS were examined in the sagittal plane and the frontal plane. Joint position sense was tested in the sagittal, frontal, and transverse planes. Because leg dominance seems to be an unrelated etiologic factor for noncontact ACL injuries,[20] only the dominant leg was tested. The dominant leg was defined as the one the subject was most comfortable jumping on. Due to the sensitivity and concentration required for the tasks, 10-minute rest between each proprioception test (including each plane of movement, ie, 60-minute rest in total) was provided. Subjects were fitted with sixteen 14-mm retroreflective markers according to the Plug-in-Gait model (Plug-in-Gait; Vicon Inc, Englewood, Colorado): Markers were placed on the heel, lateral malleolus, second metatarsal head, femoral epicondyle, and anterior superior iliac spine and posterior superior iliac spine bilaterally. Another 4 markers were placed bilaterally on the lateral side of the midthigh and midcalf. Hip joint angle data were collected and exported using Vicon Nexus software (v1.3; Vicon Inc). The Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc, Shirley, New York) was used to collect TTDPM and FS data of the hip.

A PresSsino gradient sequential compression unit and a compression sleeve (Chattanooga Group, Hixson, Tennessee) were used during the TTDPM test. The inflated pneumatic sleeve was placed around the entire leg to minimize tactile feedback between the dynamometer attachment and the limb (Figure 2).

A custom-built device was used for the active JPS testing (Figure 1). Subjects stood with 1 foot on a freely rotating turntable to be able to either externally or internally rotate the hip. The turntable had preset external and internal rotation range of motion (ROM). Subjects were instructed to slightly hold balance aids and focus on full weight bearing on both legs. The Vicon Motion Analysis System (Vicon Motion Systems Inc, Centennial, Colorado), comprised of 8 high-speed (200 Hz) infrared cameras, was utilized to track hip joint angles.

TABLE 2. Means and SDs of Absolute Errors for Joint Position Sense

	Day 1	Day 2
	Mean Absolute Error (SD)	Mean Absolute Error (SD)
ER	2.987 (2.340)	2.357 (1.691)
IR	2.547 (2.097)	2.360 (1.789)
FLEX	2.822 (2.178)	2.841 (2.246)
ABD	2.046 (1.717)	2.205 (2.035)
ADD	0.942 (0.802)	0.903 (0.780)

ABD, abduction; ADD, adduction; ER, external rotation; FLEX, flexion; IR, internal rotation.

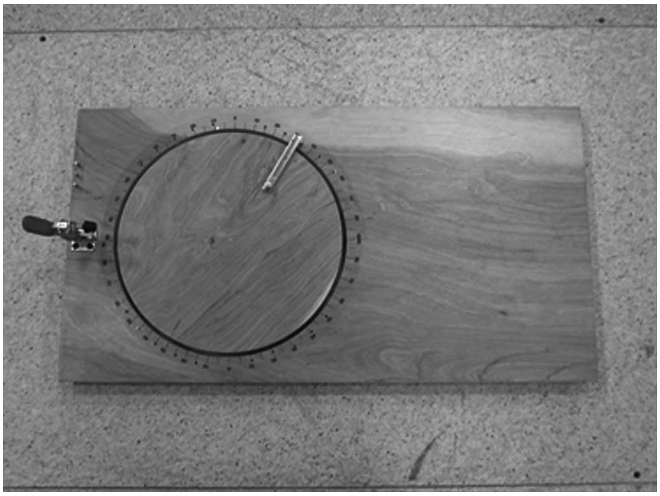

FIGURE 1. Custom-built device for internal and external rotation during active joint position sense.

Active JPS With Motion Analysis

The custom-built device was used for active JPS testing in the transverse plane (Figure 1). Subjects were tested at their maximum external and internal rotation minus 10% of the full ROM, respectively. For testing in the sagittal plane, testing started at neutral position (0 degrees in each plane) and the subject actively flexed the hip toward the flexion target position of 45 degrees. Frontal plane testing started at the neutral position with regard to the frontal plane (0 degrees of abduction/adduction) and the subject actively moved the leg toward the abduction and adduction target position of 15 degrees. Subjects were tested in a standing position and

FIGURE 2. Testing setup for flexion/extension threshold to detect passive motion.

blindfolded to eliminate visual cues. They were asked to rotate the hip to the target angle, which was set by a mechanical obstruction. Upon contact with the target position, the subjects held the position for 5 seconds and they focused and remembered what the position felt like at the hip. The task was then repeated, trying to replicate the target angle, without use of the mechanical obstruction. Once the subjects perceived the location, they were instructed to press a manual trigger. Five repetitions were performed for each leg. The start and stop angles were recorded for data analysis, with the amount of discrepancy in degrees representing the error.

Threshold to Detect Passive Motion

Subjects were blindfolded and their ears were covered by headphones playing white noise to eliminate visual and auditory cues, respectively. The subject's contralateral thigh was securely and comfortably held with a padded strap. The pneumatic sleeve was hooked to the dynamometer attachment and inflated to a minimal pressure (~40 mm Hg). At an unannounced time (~0-30 seconds), the hip moved passively at a rate of 0.25 degrees/s. The subjects were instructed to focus on their hip position and press a stop button as soon as motion was perceived and the direction of movement could be identified. The displacement between the initiation of motion and the subject's perception of motion and direction was recorded in degrees. If the subject pushed the stop button and indicated the wrong direction, that trial was excluded. The start and stop angles were recorded for data analysis.

Sagittal plane testing was done in supine position with the knee extended. The test started with the hip in 45-degree flexion. Five repetitions for each direction (flexion or extension) were performed in a randomized order (Figure 2). Frontal plane testing was done in side-lying position. The test started with the hip in 15-degree abduction. The knee was in extension during the test. Five repetitions for each direction (abduction or adduction) were performed in a randomized order (Figure 3).

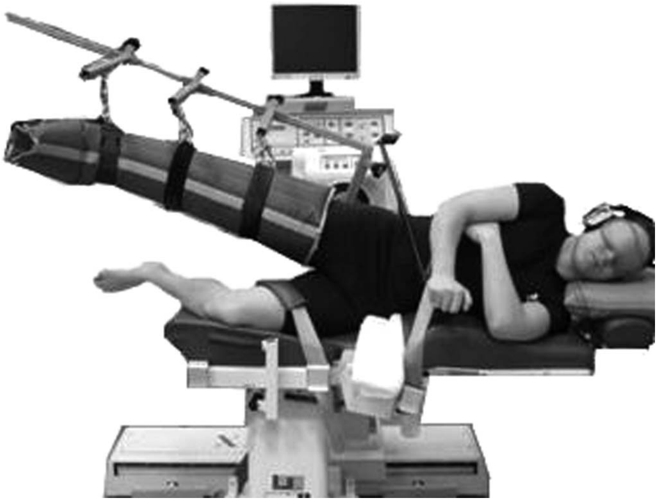

FIGURE 3. Testing setup for abduction/adduction threshold to detect passive motion.

Force Sense

Force sense was tested isometrically. The subject's ipsilateral thigh was securely held with a padded strap just above the knee. Three 5-second maximum voluntary isometric contractions (MVIC) toward extension, flexion, abduction, and adduction were performed with an interval of 10 seconds before testing in each respective direction. The maximum torques for 3 trials were averaged as the mean MVIC peak torque. Next, FS in the sagittal and frontal planes was tested. Subjects were asked to produce and target a torque in a given test direction indicated by a visual cue displayed on the dynamometer computer monitor for 5 seconds. Target torque was normalized to 25% of the subject's mean peak MVIC torque. Subjects were instructed to focus on what the force felt like at the hip. After a 5-second rest interval, the subject was asked to remember and reproduce the target torque for 5 seconds without visual feedback from the monitor. Both visual and nonvisual trials were recorded.

For testing in the sagittal plane, the subjects were tested in a supine position and the test started in 45-degree hip flexion (Figure 4). Subjects were tested in a side-lying position during frontal plane testing. The angle of the hip was held at 15 degrees of abduction during the test (Figure 5).

Data Reduction and Statistical Analysis

The variables of interest were as follows:

1. For active JPS, hip joint kinematics were evaluated at the starting and target positions. Joint kinematic data were exported to Matlab (release 7.0.4; The MathWorks, Natick, Massachusetts). Five active JPS absolute error (degrees) scores (the absolute difference between the reference and reproduction values) in the sagittal (only flexion), frontal, and transverse planes were calculated. Those 5 error scores were then averaged, giving the mean error score.
2. For TTDPM, raw torque data were recorded after every trial into Excel (Microsoft Office 2003). Five TTDPM absolute error (degrees) scores (the absolute difference between the reference and reproduction values) in the sagittal and frontal planes were calculated. Those 5 error scores were then averaged, giving the mean error score.

FIGURE 4. Testing setup for flexion/extension force sense.

FIGURE 5. Testing setup for abduction/adduction force sense.

3. For FS, the last 3 seconds of each trial were averaged. The difference between the visual and nonvisual trials was calculated and gave the variable of interest. Five FS absolute error (Newton-meters) scores (the absolute difference between the reference and reproduction values) in the sagittal and frontal planes were calculated. Those 5 error scores were then averaged, giving the mean error score.

Intraclass correlation (ICC), using the (3,k) model described by Shrout and Fleiss[21] and standard error of measurement (SEM) were used to assess the intersession and intrasession reliability and precision of the proprioception tests. SPSS 14.0 (SPSS Inc, Chicago, Illinois) was used to calculate all ICC values. As a general guideline, Portney and Watkins[22] suggest that ICC values above 0.75 are indicative of good reliability whereas those below 0.75 indicate moderate to poor reliability.

RESULTS

Joint Position Sense

Descriptive data of absolute errors are presented in Table 2. The reliability and precision results for active JPS are presented in Table 3. With an intersession ICC (SEM) of 0.753 (0.248 degrees), only adduction showed good reliability.

Threshold to Detect Passive Motion

Descriptive data of the absolute errors are presented in Table 4. The reliability and precision results for TTDPM are presented in Table 5. Good intrasession reliability was shown for hip abduction (ICC: 0.825, SEM: 0.256 degrees) and adduction (ICC: 0.765, SEM: 0.266 degrees). Good intersession reliability was shown for hip flexion (ICC: 0.810, SEM: 0.143 degrees), extension (ICC: 0.777, SEM: 0.195 degrees), abduction (ICC: 0.906, SEM: 0.176 degrees), and adduction (ICC: 0.893, SEM: 0.144 degrees).

TABLE 3. Reliability and Precision for Joint Position Sense

	Intrasession ICC	Instrasession SEM, Degrees	Intersession ICC	Intersession SEM, Degrees
ER	0.319	1.647	0.628	0.854
IR	0.159	1.765	−0.079	1.246
FLEX	0.229	1.931	0.737	0.718
ABD	0.300	1.551	0.486	0.932
ADD	0.194	0.717	0.753	0.248

ABD, abduction; ADD, adduction; ER, external rotation; FLEX, flexion; ICC, intraclass correlation; IR, internal rotation; SEM, standard error of measurement.

TABLE 4. Means and SDs of Absolute Errors for Threshold to Detect Passive Motion

	Day 1	Day 2
	Mean Absolute Error (SD)	Mean Absolute Error (SD)
FLEX	0.544 (0.351)	0.542 (0.429)
EXT	0.641 (0.398)	0.710 (0.573)
ABD	0.626 (0.672)	0.606 (0.554)
ADD	0.719 (0.570)	0.700 (0.473)

ABD, abduction; ADD, adduction; ER, external rotation; FLEX, flexion; IR, internal rotation.

Force Sense

Descriptive data of the absolute errors are presented in Table 6. The reliability and precision results for FS are presented in Table 7. Only flexion showed good intersession reliability (ICC: 0.764, SEM: 0.932 Nm).

DISCUSSION

The overall objective was to determine if the hip (position and motion) may contribute to the function of the knee and ultimately increase the risk of ACL injury. The necessary first step and purpose of this study was to establish the intersession and intrasession reliability and precision for hip proprioception tests of the hip in healthy individuals.

Active JPS

The majority of JPS measurements (7 of 8) did not show good reliability (Table 3). Despite the poor reliability, the means and SDs were consistent between day 1 and day 2 measurements and show promising results. For internal rotation, the intersession ICC of −0.079 cannot be considered valid and the negative outcome might have been due to homogeneity of the group responses (healthy subjects).

Previous research reported good to moderate reliability and precision for JPS.[23] Overall, our study did not show satisfactory results. Potential reasons for the poor results may be related to the difficulty in task performance. Great effort was made to ensure the subjects' comfort and safety. However,

TABLE 5. Reliability and Precision for Threshold to Detect Passive Motion

	Intrasession ICC	Intrasession SEM, Degrees	Intersession ICC	Intersession SEM, Degrees
FLEX	0.603	0.219	0.810	0.143
EXT	0.540	0.310	0.777	0.195
ABD	0.825	0.256	0.906	0.176
ADD	0.765	0.266	0.893	0.144

ABD, abduction; ADD, adduction; ER, external rotation; FLEX, flexion; ICC, intraclass correlation; IR, internal rotation; SEM, standard error of measurement.

TABLE 6. Means and SDs of Absolute Errors for Force Sense

	Day 1	Day 2
	Mean Absolute Error (SD)	Mean Absolute Error (SD)
FLEX	3.9 (3.7)	3.4 (2.9)
EXT	3.6 (3.6)	4.7 (3.5)
ABD	3.8 (3.0)	3.5 (2.7)
ADD	2.7 (2.1)	3.5 (3.9)

ABD, abduction; ADD, adduction; ER, external rotation; FLEX, flexion; IR, internal rotation.

when testing in a single-legged standing position with the eyes blindfolded, the subjects had to focus on maintaining balance. This could have affected their ability to solely focus on the tested hip. Improvements in active JPS procedures may include testing abduction, adduction, flexion, and extension using the Biodex System 3 (Biodex Medical Inc). Both procedures (standing vs lying down) will be open kinetic chain, so it might be worthwhile to consider testing in a supine or side-lying position instead of a standing position even though the advantage of a standing position is that it better reflects joint positions during functional activities and sport. The advantage of testing in a supine or side-lying position is that the subject will have more support and will be better able to focus on the hip joint. No focus will be necessary to keep balance. Also, the leg will be guided as the leg will be attached to the dynamometer. This will in all likelihood create more consistency across trials. In summary, using the Biodex System 3 may minimize confounding factors affecting the test procedures.

Threshold to Detect Passive Motion

For the majority, the TTDPM measurements (6 of 8) showed good reliability (Table 5). Previous research has also presented good reliability and precision TTDPM data for the knee.[24]

An inflated pneumatic sleeve was used during testing TTDPM with the Biodex System 3 to minimize tactile feedback and allowed the subject to focus on hip movement. This created a controlled position and likely contributed to the good results.

Force Sense

The majority of FS measurements (7 of 8) did not show good reliability (Table 7). Force sense has been reported to have good reliability and precision values in other research.[23,25]

Reasons for poor reliability found in this study are likely multifactorial. Force sense testing toward abduction did show the worst reliability. Based on observations and subject feedback, a potential reason for this could be that it was hard to maintain the required side-lying posture with the hip in neutral position and still produce the force. When holding the test position, the tensor fasciae latae, the gluteus medius, and the gluteus minimus were the intended muscles to be tested. Even though the subjects were properly strapped, they had the tendency to externally rotate the hip to be able to recruit more muscle fibers, particularly from the hip flexors. Clear instructions, however, were given to solely abduct the hip, which possibly resulted in performing a task that was hard to perform. A potential solution to this could be reducing the %MVIC target or time of contraction.

TABLE 7. Reliability and Precision for Force Sense

	Intrasession ICC	Intrasession SEM, Nm	Intersession ICC	Intersession SEM, Nm
FLEX	0.168	3.019	0.764	0.923
EXT	0.372	2.812	0.639	1.502
ABD	0.030	2.807	0.171	1.184
ADD	0.344	2.405	0.428	1.664

ABD, abduction; ADD, adduction; ER, external rotation; FLEX, flexion; ICC, intraclass correlation; IR, internal rotation; SEM, standard error of measurement.

Also, testing toward flexion did reveal some issues. Despite best efforts to be consistent across all subjects in informing the subjects that they should focus on moving the hip and eliminate using other body parts to generate force, observation during testing revealed that subjects adopted different strategies. Future research should focus on trying to better isolate the hip. Even though this was probably the best position possible (standing would allow for even more additional movements), it is recommended to continue looking for ways to strap and position the subjects securely.

It may also be possible that the FS methodology utilized in this study does not target the appropriate mechanisms by which we can examine neuromuscular control. Future research should try to find other research methodologies to potentially better target the muscle spindle sensitivity.

Potential Sources for Less Reliable Results

The proprioception methodology applied to the hip in this study was new compared with that in other research studies.[14,15,17,26] In this study, the Biodex System 3 was used for TTDPM and FS. Although efforts were made to minimize cutaneous feedback during TTDPM testing, potential sources could have included friction force between the gluteal region and the seat and feedback from the spandex shorts. Attempts to standardize friction force and folding clothes across all subjects were made as all subjects wore spandex shorts. To our knowledge, no one has ever tested the contribution of friction force and folding clothes on cutaneous feedback.

The pneumatic sleeve used for TTDPM may have diminished the external cutaneous input, thereby improving the potential validity of data collection. However, this is unclear as a large area of contact in general may enhance proprioception consistent with the use of bracing.[27–32] The large pneumatic sleeve attached to the subject's leg may therefore have provided enough external stimuli to alter the subject's natural internal proprioception through cutaneous mechanoreceptor stimulation.[33]

Nonnormalized test positions relative to an individual's available hip ROM potentially affected the consistency of testing between days. Variability in performance across subjects due to different available hip ROM could have contributed to poor ICC values as joint angle is a factor that has been shown to affect the perception of movement. For the knee, it is suggested that articular mechanoreceptors are most active at the extremes of joint position.[34–37] When applied to this study, 15-degree abduction and 45-degree flexion are not the extremes of hip ROM. During testing, we have not excessively stressed the ligamentum capitis femoris or the acetabular labrum, and these structures therefore probably have not provided the subjects with afferent signals. But the compression caused by the periarticular musculoskeletal system will in all likelihood have been registered by the mechanoreceptors present in these structures.[38] Fifteen-degree hip abduction has been chosen to replicate the hip position at landing.[3] Testing in 45-degree hip flexion was selected due to the constraints of participant positioning as it was the test position in which it was possible to cover the entire leg with the pneumatic sleeve without touching the chair (which could give potential external sensory input). Considering the results of Krosshaug et al,[3] athletes do not land in their end ROM of flexion. Testing in 45-degree hip flexion might therefore better replicate the hip joint angle at landing compared to testing near end ROM.

Instrumentation error may contribute to the outcome error and should be considered in discussion. Based on unpublished laboratory validation comparing the Vicon system to a Microscribe, we estimate the root mean square error of the motion capture system to be 0.39 mm and 0.08 degrees for a given data capture. Previous literature for reliability of hip kinematics have reported peak angle within-day (intrasession) ICCs of 0.98 (extension and internal rotation) and 0.99 (adduction)[39] and between-day (intersession) ICCs of 0.54 (internal rotation), 0.69 (adduction), and 0.88 (extension)[39] for similar motion capture systems. The ICCs in this study are generally lower (Table 2), and the differences can be attributed to methodology across referenced studies.

Applicability

It is difficult to predict to what extent the observed proprioception capacities of the subjects in a laboratory setting expose the athlete to increased risk of injury on the field.[40] The testing procedures examined in this study represent conscious proprioception in positions not reflecting the actual positions during sports. Proprioception involves the unconscious control and perception of movement. This aspect is more likely involved in injury because it is responsible for the immediate response to the unpredicted perturbation that can happen to the athlete during sport and the nonathlete during function. The feedfoward and feedback mechanisms in real time do not occur consciously. The methodology employed in this study can therefore not make any judgment related to unconscious control and function after injury, making further research necessary to address this issue.

CONCLUSIONS

For TTDPM, the intrasession ICC toward flexion and extension was the only variable that showed moderate reliability. All the other ICCs (intersession and intrasession toward the other directions) of TTDPM had an ICC of >0.75 (Table 6). These results indicate that a reliable and precise method of measuring hip TTDPM toward flexion, extension, abduction, and adduction has been established in a young and healthy population. Future research can implement TTDPM methodology to further investigate the role of TTDPM in pathology. Further investigation is, however, warranted to further develop reliable and precise measurement methods for FS and active JPS measurements of the hip. Investigating the relationship between neuromuscular control and proprioception and to functional task performance is warranted.

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