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Original research

Reliability, precision, and gender differences in knee internal/external rotation proprioception measurements

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A B S T R A C T

Objective: To develop and assess the reliability and precision of knee internal/external rotation (IR/ER) threshold to detect passive motion (TTDPM) and determine if gender differences exist.
Design: Test–retest for the reliability/precision and cross-sectional for gender comparisons.
Setting: University neuromuscular and human performance research laboratory.
Participants: Ten subjects for the reliability and precision aim. Twenty subjects (10 males and 10 females) for gender comparisons.
Intervention: All TTDPM tests were performed using a multi-mode dynamometer. Subjects performed TTDPM at two knee positions (near IR or ER end-range). Intraclass correlation coefficient (ICC (3,k)) and standard error of measurement (SEM) were used to evaluate the reliability and precision. Independent *t*-tests were used to compare genders.
Main outcome measurements: TTDPM toward IR and ER at two knee positions.
Results: Intrasession and intersession reliability and precision were good (ICC = 0.68–0.86; SEM = 0.22°–0.37°). Females had significantly diminished TTDPM toward IR at IR-test position (males: 0.77° ± 0.14°, females: 1.18° ± 0.46°, $p = 0.021$) and TTDPM toward IR at the ER-test position (males: 0.87° ± 0.13°, females: 1.36° ± 0.58°, $p = 0.026$). No other significant gender differences were found ($p > 0.05$).
Conclusions: The current IR/ER TTDPM methods are reliable and accurate for the test–retest or cross-section research design. Gender differences were found toward IR where the ACL acts as the secondary restraint.

1. Introduction

The importance of the sensorimotor system (encompassing sensory information, central processing and integration, and neuromuscular control) in maintaining a stable knee joint has been widely recognized (Lephart, Riemann, & Fu, 2000). Proprioception is an important component of the sensorimotor system as it provides information regarding joint position sense, kinesthesia, and sense of heaviness (Lephart et al., 2000). The anterior cruciate ligament (ACL) contains mechanoreceptors and plays an important role in knee proprioception, and its role has been studied and reviewed previously (Johansson, Sjolander, & Sojka, 1991; Schutte, Dabezies, Zimny, & Happel, 1987). Loading of the ACL causes changes in the firing of the mechanoreceptors and elicits reflex activation of the hamstring muscles (Johansson, Sjolander, & Sojka, 1990; Solomonow et al., 1987). Furthermore, diminished knee flexion and extension proprioception have been reported in clinical studies with ACL deficiency and following ACL reconstruction (Barrack, Skinner, & Buckley, 1989; Barrett, 1991; Borsa, Lephart, Irrgang, Safran, & Fu, 1997; Corrigan, Cashman, & Brady, 1992; Iwasa, Ochi, Adachi, Tobita, Katsube, & Uchio, 2000).

To date, knee proprioception research has primarily focused on the sensory role of the ACL in the sagittal plane, but the ACL functions in all three planes. Cadaveric studies have demonstrated that the ACL acts as a primary restraint to anterior tibial translation and secondary restraint to both valgus/varus and internal and external rotation (IR/ER) loading (Butler, Noyes, & Grood, 1980; Markolf, Gorek, Kabo, & Shapiro, 1990). In a normal knee, there are approximately 57° and 74° in knee IR/ER active and passive range of motion, respectively (Osternig, Bates, & James, 1980; Zarins, Rowe, Harris, & Watkins, 1983). During treadmill running, there are approximately 10° in knee IR/ER (Tashman, Collon, Anderson, Kolowich, & Anderst, 2004). Following ACL injury, knee IR/ER range of motion and kinematics are altered (Andriacchi, Briant, Bevill, & Koo, 2006; Tashman, Kolowich, Collon, Anderson, & Anderst, 2007; Zarins et al., 1983) and the altered kinematics

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may be associated with a lack of mechanical restraint and sensory feedback from the ACL. Non-contact ACL injuries likely occur during the initial phase of foot-ground-contact with knee extension, knee valgus, and/or knee IR/ER (Boden, Dean, Feagin, & Garrett, 2000; Olsen, Myklebust, Engebretsen, & Bahr, 2004). A lack of knee IR/ER proprioception may be a contributing factor to the higher rate of ACL injury in female athletes (Agel, Arendt, & Bershadsky, 2005; Arendt, Agel, & Dick, 1999).

Previous research has explored the reasons for the greater rate of the ACL injury in female athletes compared to male athletes including an examination of potential risk factors through gender comparison studies (Hewett, Myer, & Ford, 2006; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Rozzi, Lephart, Gear, & Fu, 1999; Sell et al., 2006). However, gender differences in knee proprioception have rarely been studied. One study has indicated diminished knee flexion/extension threshold to detect passive motion (TTDPM) in female subjects (Rozzi et al., 1999). Previous research has only looked at knee flexion and extension proprioception, but due to the role of the ACL as the secondary restraint to knee IR/ER coupled with the rotary component of the non-contact ACL injury mechanism, research of knee IR/ER proprioception seems warranted (Markolf et al., 1990). We are aware of only one study that has evaluated knee IR/ER proprioception using an absolute judgment task (in which participants actively rotate IR/ER, while a tester changes the end-range of IR/ER motion, and try to judge the magnitude of changes in the end-range) and reported the reliability of 0.55 (Muaidi, Nicholson, Refshauge, Adams, & Roe, 2009). Due to the limited research on this topic with inconclusive results, it is essential to develop a reliable and precise method to measure knee IR/ER proprioception.

The objectives of the study were to develop and assess the reliability and precision of knee IR/ER TTDPM and compare between genders. It was hypothesized that knee IR/ER TTDPM methods would result in good reliability and precision. It was also hypothesized that there would be significant differences between genders, with females demonstrating diminished TTDPM compared to males.

2. Methods

2.1. Subjects

Twenty healthy (10 males and 10 females) subjects were recruited from the University. The first five male and five female subjects reported to the laboratory for two sessions to evaluate the intersession reliability and precision. The remaining 10 subjects reported for only one testing session. Subjects provided written informed consent prior to participation in accordance with the University Institutional Review Board. Subject demographics (age, height, and mass) are shown in Table 1. All subjects were physically active, defined as participating in exercise for at least 30 min a day for three times a week. Exclusion criteria included a history of any major lower extremity injuries that required surgery.

2.2. Procedures

All TTDPM data were collected with the Biodex System 3 Multi-Joint Testing and Rehabilitation System utilizing the Research Toolkit software application (Biodex Medical Inc., Shirley, NY). The reliability and validity of the dynamometer hardware has been previously reported (ICC = 0.99–1.00) (Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004). Threshold to detect passive motion is shown to be velocity-dependent, and subjects have higher thresholds (more difficult to detect) at a slower velocity (Refshauge, Chan, Taylor, & McCloskey, 1995). Therefore, we selected the slowest velocity (a rate of 0.25°/s) available in the dynamometer hardware. The dominant leg was used for all tests, and was operationally defined as the leg preferred to kick a ball.

Fig. 1. Subject setting on IR/ER proprioception.

Subjects were seated in a dynamometer chair with their knee and hip positioned at 90° flexion (Fig. 1). Knee IR/ER movement was isolated by stabilizing each subject with a padded strap at mid-thigh, a strap at the hip, and two straps crossing in front of the chest. An air pneumatic boot (FP walker boots, Aircast, Summit, NJ) was applied to the dominant leg, fixing the ankle at 0° plantar flexion. The boot was securely attached to the dynamometer and the air cushion in the boot was inflated to conform around the ankle and lower leg to minimize tactile sensation (Horch, Clark, & Burgess, 1975). Subjects were blindfolded and listened to static noise through headphones to eliminate visual and auditory cues during actual testing.

Once subjects were secured comfortably on the dynamometer chair, subjects actively rotated the knee toward IR/ER end-range positions. Active range of motion for IR, ER, and a combined IR/ER is shown in Table 2. Initial joint position can influence the sensitivity of TTDPM (more sensitive near end-range than the middle range); therefore, the tests were conducted near IR/ER end-range (Lephart, Kocher, Fu, Borsa, & Harner, 1992). The following three reference positions (Fig. 2) were determined: 1) IR/ER neutral position in which the boot is positioned vertical and aligned with 12 o'clock position of the dynamometer; 2) IR-test position, defined as 10° less than the maximum IR end-range position; and 3) ER-test position, defined as 10° less than the maximum ER end-range position.

First, TTDPM testing began with the knee at the IR-test position. At an unannounced time (0–30 s), the knee was passively moved into either IR or ER at a rate of 0.25°/s. Subjects were instructed to

Table 1
Subject demographics: mean (±SD).

	Males	Females
Age (years)	24.7 (±4.2)	21.7 (±2.1)
Height (cm)	183.1 (±8.2)	166.4 (±9.0)
Mass (kg)	81.4 (±9.3)	59.7 (±8.2)

Table 2
Active range of motion for IR, ER, and combined: mean (±SD).

	Males	Females
Internal rotation (°)	29.9 (±4.8)	30.6 (±4.7)
External rotation (°)	38.0 (±8.3)	38.9 (±6.3)
Combined (°)	68.0 (±10.3)	69.6 (±9.9)

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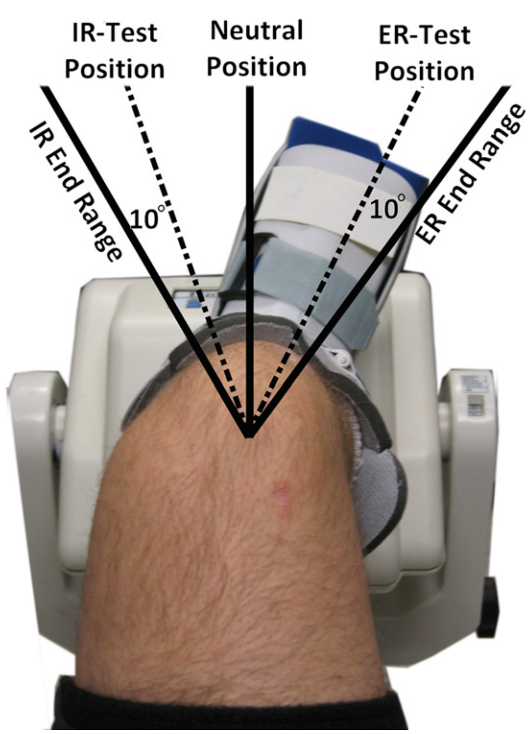

Fig. 2. Close-up view of IR/ER end-range determined during active ROM and three reference positions.

press a stop-button as soon as he or she perceived movement and direction (either toward IR or toward ER). Subjects were asked to report which direction their limb moved after pressing the stop-button. If the subject pushed the stop-button and answered the wrong direction, the trial was discarded. Three practice trials were provided prior to testing. Five trials each for IR and ER were randomly performed at the IR-test position. The difference between the initial position and the final position was calculated as TTDPM. The same procedure was repeated starting in the ER-test position.

2.3. Data reduction

The average of five TTDPM trials were used for analyses for both IR and ER from each test position. Four dependent variables of interest were identified: TTDPM toward IR at the IR-test position, TTDPM toward ER at the IR-test position, TTDPM toward IR at the ER-test position, and TTDPM toward ER at the ER-test position.

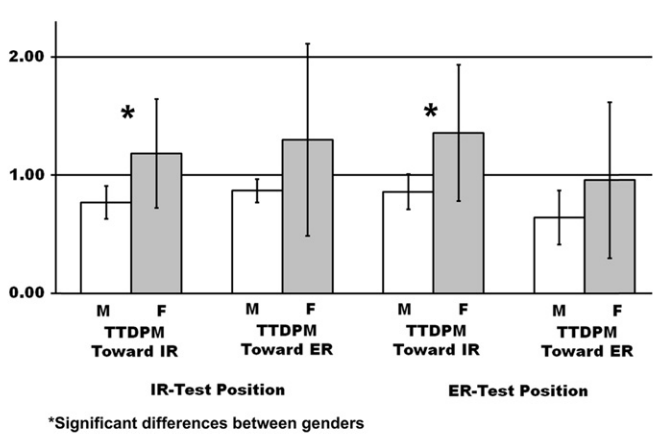

Fig. 3. Summary of gender differences in knee IR/ER TTDPM. Error bars represent ± SD.

2.4. Statistical analysis

Intraclass correlation coefficients (ICC) using the (3,k) model and standard error of measurement (SEM) were used to assess the intrasession and intersession reliability and precision. For gender comparisons, means, standard deviations, 95% confidence intervals of all four dependent variables were calculated. Independent *t*-tests with an alpha value of 0.05 a priori were used to evaluate gender comparisons. All statistical procedures were performed in SPSS 17.0 (SPSS, Inc., Chicago, IL).

3. Results

All intrasession and intersession ICC and SEM are presented in Table 3. The intrasession ICC and SEM were 0.72–0.86 and 0.25–0.35°, respectively. The intersession ICC and SEM were 0.68–0.85 and 0.22–0.37°, respectively.

All TTDPM variables for males and females and gender comparison results are presented in Table 4. Females demonstrated significantly diminished TTDPM toward IR at the IR-test position (males: 0.77°, females: 1.18°, $p = 0.021$) and TTDPM toward IR at the ER-test position (males: 0.87°, females: 1.36°, $p = 0.026$). No other significant gender differences were found with the remaining variables ($p > 0.05$).

4. Discussion

The objective of the study was to develop and assess the reliability and precision of methodology to examine TTDPM of knee IR/ER and determine if gender differences exist. It was hypothesized that a methodology to examine TTDPM in the transverse plane would result in good reliability and precision. This hypothesis was support as the intrasession and intersession reliability was greater than 0.75 on average, suggesting that reliable measurements of knee IR/ER proprioception can be obtained in a single or multiple sessions. Additionally, it was hypothesized that there would be significant differences between genders with females demonstrating diminished TTDPM compared to their male counterparts. This hypothesis was partially supported as significant differences were demonstrated between genders for 50% (2 out of 4) dependent variables (Fig. 3).

The current study had ICC from 0.72 to 0.86 and from 0.68 to 0.85 for intrasession and intersession analyses, respectively. A previous study has indicated similar intersession reliability (ICC = 0.83) using knee flexion/extension TTDPM tests (Beynnon, Renstrom, Konradsen, Elmqvist, Gottlieb, & Dirks, 2000). The authors also evaluated the reliability using various joint position sense (JPS) tests and concluded that TTDPM tests were the most reliable proprioception test (Beynnon et al., 2000). Other studies have indicated the deficits in TTDPM, but not in JPS, after ACL injury compared to a non-injured control group (Ozenci et al., 2007; Reider et al., 2003). Good reliability and precision in the current study would help researchers and clinicians to further evaluate the effects of the anatomic ACL reconstruction or rehabilitation for individuals with rotational instability.

Table 3
Knee IR/ER TTDPM reliability and precision: ICC (±SEM).

	Intrasession	Intersession
At IR-test position		
TTDPM toward IR	0.86 (±0.27°)	0.83 (±0.22°)
TTDPM toward ER	0.72 (±0.35°)	0.84 (±0.27°)
At ER-test position		
TTDPM toward IR	0.78 (±0.34°)	0.68 (±0.37°)
TTDPM toward ER	0.76 (±0.25°)	0.85 (±0.25°)

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Table 4
Knee IR/ER TTDPM gender comparison: mean (±SD) and 95% confidence interval.

Variable	Males	95% CI	Females	95% CI	p-Value
At IR-test position					
TTDPM toward IR	0.77° (±0.14°)	0.24–1.30	1.18° (±0.46°)	0.65–1.71	0.021*
TTDPM toward ER	0.87° (±0.10°)	0.18–1.56	1.30° (±0.81°)	0.61–1.99	0.130
At ER-test position					
TTDPM toward IR	0.87° (±0.13°)	0.20–1.54	1.36° (±0.58°)	0.69–2.03	0.026*
TTDPM toward ER	0.64° (±0.23°)	0.15–1.14	0.96° (±0.66°)	0.47–1.45	0.179

*Significant differences between genders.

As a general guideline, the ICC values above 0.75 are considered as good to excellent reliability (Portney & Watkins, 2000). Landis and Koch (1977) further subdivide them to 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–0.99 almost perfect agreement. A recent study has indicated moderate reliability (ICC = 0.55) with a knee IR/ER proprioception acuity method, in which subjects rotate their knee actively and detect the differences in the magnitude of rotation from the previous trial (Muaidi et al., 2009). Based on the previous and current reliability values, the current method provides researchers and clinicians a reliable means of evaluating knee IR/ER proprioception.

The current study had a SEM from 0.25 to 0.35° and from 0.22 to 0.37° for intrasession and intersession analyses, respectively. Since few studies have reported SEM, it is not possible to evaluate if the current results are in accordance with previous research. The SEM reflects the reliability of the response and is calculated based on the group standard deviation and the reliability coefficient (Portney & Watkins, 2000). The current procedures for knee IR/ER TTDPM were developed based on the previous studies on knee flexion/extension TTDPM (Lephart, Fu, & Borsa, 1994; Lephart, Giraldo, Borsa, & Fu, 1996). The current results (means: 0.64–1.36°; SD: 0.10–0.81°) had similar means and standard deviations, reported in previous TTDPM studies (means: 1.04–1.10°; SD: 0.18–0.50°) (Corrigan et al., 1992; Lephart et al., 1996), suggesting that the current procedures were properly executed.

Clinically, a SEM value is important because it could be used for a reference for future studies. A confidence interval can be calculated based on observed means and SEM (95% confidence interval = observed score ± 1.96*SEM) to estimate the group's true mean score and provide a benchmark for evaluating individual performance over time (Portney & Watkins, 2000). Based on the current confidence interval, the group's true mean score for knee IR/ER TTDPM falls between 0.15°–0.24° and 1.14°–1.56° for males and between 0.47°–0.69° and 1.45°–2.03° for females with 95% confidence (Table 4). It was observed that the upper limit for the 95% confidence interval for females was on average 0.41° higher than males. Researchers and clinicians should be aware of the gender difference when using the true mean score as a benchmark.

In the current study, females demonstrated diminished TTDPM motion toward IR compare to males (Fig. 3). Previously, only a few studies have evaluated gender differences in knee proprioception with knee flexion/extension TTDPM, and females have TTDPM toward extension near the end-range (Barrack, Skinner, Brunet, & Cook, 1984; Rozzi et al., 1999). The current and previous results suggest gender differences are only present in the directions where the ACL can be loaded (toward full extension and internal rotation) (Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauterbeck, 1995). Diminished TTDPM could mean that it takes longer for female athletes to sense dangerous positions that resemble non-contact ACL injury patterns (Boden et al., 2000; Olsen et al., 2004). Female athletes also provide less tibial ER muscular torque to counterbalance IR torque, resulting in less torsional stiffness (Wojtys, Huston, Schock, Boylan, & Ashton-Miller, 2003). Although the TTDPM difference between genders does not indicate the cause of injury, it does provide insight to potential risk of injury and demonstrates the usefulness of knee TTDPM measures for future risk factor studies.

There are limitations to the current study. One potential limitation is the sample size. Post-hoc analyses revealed that the variables with statistical significance had large effect sizes (Cohen's $d = 1.044$ and 1.025 for TTDPM toward IR at the IR-test position and at the ER-test position, respectively). However, based on the observed effect size, in order to achieve an alpha value of 0.05 and the power of 0.80, the study required 13 subjects in each group. A larger sample size might minimize the probability of a type II error. A larger sample size would also permit further analyses to be performed such as a two-way ANOVA to determine between movements regardless of gender. Another potential limitation is that no joint laxity tests were conducted in the current investigation. A previous study has indicated that general joint laxity has an influence on proprioception (Roberts, Ageberg, Andersson, & Friden, 2007). The current study did not conduct joint laxity tests; therefore, it is impossible to determine if general joint laxity could have been a confounding variable. Instead, active range of motion was measured, and there was no gender difference. Although it is speculative, joint laxity tests would likely have minimal influence on the current findings in the current method. Third, the subjects were tested in a seated position in the current investigation. While this position was effective in stabilizing the ankle, thigh, and hip to isolate knee IR/ER, it could be argued that the position is not weight-bearing and functional.

5. Conclusions

The current study demonstrated a reliable and precise method to assess knee IR/ER TTDPM. Gender differences were found toward IR where the ACL acts as a secondary restraint. A lack of proprioceptive feedback could lead to altered neuromuscular control, predisposing female athletes to risk of non-contact ACL injury. Although the gender differences demonstrated in the current study do not establish a cause-and-effect relationship between TTDPM and non-contact ACL injury, important evidence is provided that can direct future prospective studies that include injury surveillance and proprioception testing. In addition, it would be clinically important to include this measurement in future studies examining rehabilitation strategies following ACL injury, ACL reconstruction to restore the rotational stability, and ACL injury prevention programs.

Conflict of interest

None declared.

Ethical approval

The University of Pittsburgh Institutional Review Board (IRB) approved this study. All participates received verbal and written information about the study and gave written informed consent prior to measurement.

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