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Estimation-based joint position sense: comparing self-rated and measured accuracy across sexes

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ABSTRACT

Background: The validity of self-rated joint position sense (JPS) remains inconclusive. Moreover, previous experimental designs for JPS assessment often failed to reflect real-life movement execution, and studies addressing sex differences in JPS are limited. Therefore, this study aimed to investigate the relationship between perceived JPS (self-rated JPS) and actual joint position error (JPE), and examine sex-based differences in JPE.

Methods: Thirty-three apparently healthy adults participated in the study and performed an elbow flexion to 90°, relying on proprioceptive inference rather than memorized reproduction. Ordinal logistic regression was used to analyze the relationship between the perceived JPS and JPE. JPS acuity was evaluated using constant error and absolute error (AE), while the reliability of repeated measures was assessed using the intraclass correlation coefficient (ICC).

Results: Ordinal logistic regression revealed that higher JPE values are associated with lower self-ratings of JPS ability. In the analysis of sex differences, females exhibited significantly greater AEs than did males, indicating lower proprioceptive accuracy. However, ICC values showed slightly higher reliability in females, suggesting more consistent performance across repeated trials despite larger deviations from the target angle.

Conclusion: This study provides new evidence on the relationship between self-perceived and measured JPS, as well as sex-related differences in proprioceptive performance. The findings underscore the importance of considering sex and individual self-awareness in proprioceptive training strategies. Therefore, incorporating cognitive feedback may enhance JPS self-perception and improve training outcomes in clinical and sporting contexts.

Keywords: elbow joint, position sense, proprioception, reproduction.

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INTRODUCTION

In a self-rated assessment, individuals subjectively evaluate and report their physical functions.[1] This approach has been widely acknowledged as a valuable evaluation tool in clinical and sports science. Despite its subjectivity, numerous studies have consistently demonstrated that self-rated evaluations show significant correlations with key quantitative health outcomes.[2] One of the most representative examples is self-rated health status, which serves as a simple yet powerful indicator of the overall health condition of an individual. It is highly correlated with objective health indicators, such as mortality rates and disease incidence.[3,4]

This implies that individuals can assess their health conditions with relative ease, and a reasonable degree of accuracy, even without visiting medical facilities. Another notable example is self-rated exertion, commonly assessed through the Rating of Perceived Exertion (RPE). This method has been validated in numerous specialized studies as being closely associated with physiological responses, such as heart rate and blood lactate levels.[5-7] Hence, RPE is frequently used as a reference for controlling exercise intensity and designing training programs. These research findings support the use of self-rated methods as reliable indicators for evaluating physical function.

The self-rated approach may also be applicable to the evaluation of joint movement and position sense. Joint position sense (JPS), a component of proprioception, refers to the ability to perceive and control the spatial orientation of body parts.[8,9] Prior research has examined other aspects of proprioception, such as force sense, and studies exploring self-rated force production have revealed significant correlations between perceived and actual force outputs.[10] These findings suggest that individuals possess a certain level of awareness and control over their muscular contractions. Therefore, JPS could also be evaluated using self-rated methods; however, limited research has been conducted in this area. Additionally, traditional JPS assessment paradigms often do not reflect the realities of daily functional movement.

Typically, JPS is assessed by asking participants to either replicate a target joint angle with the opposite limb or reproduce a memorized angle using the same limb.[8,11,12] However, in real-life situations, movements are rarely performed based on prior memorization or bilateral matching.

Most daily or sport-related movements are executed spontaneously, without prior exposure to specific target angles. In contrast to JPS, force sense research encompasses paradigms that involve inferring target force levels, such as performing at 50% of maximum voluntary isometric contraction, in addition to standard matching tasks.[10,13] Another limitation in existing JPS research is the lack of exploration of sex differences. Although males and females may differ in terms of anatomical structure, sensory processing, and motor control strategies, studies investigating sex-based variations in JPS remain scarce.[14-17] Studies have analyzed these differences in the lower limbs; however, relatively few have examined the upper limbs, where joint positioning and proprioceptive demands are also significant.[18-20]

Given these gaps, the present study aimed to analyze the relationship between self-rated JPS and objectively measured joint position error (JPE), while also examining sex-related differences in JPS. To address the limitations of previous methodologies, the current study employed a more rigorous experimental design. The purpose of this study was to examine the following: (1) whether there is a significant correlation between self-rated joint position sense (JPS) and objectively measured joint position error (JPE), and (2) whether there are differences in JPS accuracy between male and female participants.

METHODS

Thirty-three apparently healthy adults participated in this study. Inclusion criteria were healthy adults with no current pain or injury in the upper limbs. Individuals with neurological or musculoskeletal disorders affecting the upper extremities were excluded. Additionally, participants who had experienced upper limb pain within the past six months were ineligible. The study was approved by the Institutional Review Board of Woosong University (IRB No. 1041549-241008-SB-196), and informed consent was obtained from all participants prior to participation.

The experiment was designed to evaluate proprioceptive function under conditions that minimized external sensory input, allowing participants to concentrate solely on their internal sense of joint position. During the preparatory phase, participants were seated in a chair with a backrest to maintain a stable and upright posture, and without armrests to enable unrestricted arm movement. The examiner provided a detailed explanation of the procedures before initiating the test. To eliminate visual cues that could interfere with proprioceptive accuracy, participants were instructed to keep their eyes closed throughout the evaluation, except when observing the demonstration of the examiner.

Prior to the task, the posture of each participant was adjusted to align the trunk vertically with the ground. Both arms were placed comfortably alongside the torso in a relaxed position. The examiner intervened only to guide postural corrections and avoided any physical contact during the movement execution to ensure minimal external influence on proprioceptive performance.

The elbow flexion to 90° task was designed to be completed without prior exposure to or memorization of the target angle. Unlike conventional matching tasks that rely on the replication of pre-experienced positions, this study employed an inference-based approach, requiring participants to rely solely on their proprioception. Participants first observed a demonstration of the elbow flexion movement performed by the examiner. Subsequently, they closed their eyes and, upon a start signal, actively raised their forearm to what they perceived as 90° elbow flexion. Once the participant reached the perceived target position, the experimenter measured the achieved joint angle using an inertial measurement unit sensor (Physio link, Physio Inc., Daejeon, Korea). This process was repeated under the same conditions to obtain a second estimation of the perceived target angle.

After completing the examinations, constant error (CE) and absolute error (AE) were determined, using the following equations.[21]

$$Constant\ Error = \left(\frac{1}{n}\right)\sum_{i=1}^{n}(\theta_i - \theta_t)$$

$$Absolute\ Error = \left(\frac{1}{n}\right)\sum_{i=1}^{n}|\theta_i - \theta_t|$$

where θi corresponds to the estimated joint angle of the participant and θt specifies the designated target angle.

The Shapiro–Wilk test was employed to assess the normality of all variables. To investigate the relationship between the self-perceived JPS and the actual JPE, an ordinal logistic regression analysis was conducted. In this model, self-rated JPS served as the dependent variable, while AE was treated as the independent variable. The analysis determined whether higher JPE levels correlated with lower ratings of proprioceptive ability. Model fit was evaluated using the model fitting information, Pearson and Deviance goodness-of-fit tests, and a test of parallel lines. The explanatory power of the model was assessed using pseudo-R^2 values.

Sex differences were examined using both independent samples *t*-tests and Mann–Whitney U tests. Variables such as age, height, weight, BMI, self-rated JPS, average estimated angle, and CE met the assumption of normality and were analyzed using independent *t*-tests. For variables that did not satisfy normality assumptions, particularly AE, the non-parametric Mann–Whitney U test was applied.

To evaluate the reliability of repeated measurements, the intraclass correlation coefficient (ICC) was calculated using the estimates from the first and second trials. A two-way mixed-effects model, based on a consistency definition, was used to compute ICCs for all the participants and the male and female subgroups.

All statistical analyses were performed using IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA), with the significance level (α) set at 0.05.

RESULTS

The average age of participants was 23.36 ± 2.32 years; height, 167.91 ± 10.39 cm; body weight, 70.48 ± 15.04 kg; and body mass index (BMI), 24.88 ± 4.10 kg/m^2 (**Table 1**). While males had significantly higher height and weight than females, there were no significant differences in BMI or age, indicating comparable body mass relative to height and similar age distribution.

A comparison of the self-rated JPS scores revealed no significant differences between male and female participants, with both groups reporting a mean score of 6.6 ($t(31) = -0.026$, $P = 0.979$) (**Figure 1**). The ordinal logistic regression analysis demonstrated that AE had a significant effect on the self-rated JPS scores ($\beta = -0.111$, $P = 0.026$) (**Figure 2**). This suggests that participants with higher JPE were more likely to rate their proprioceptive ability lower.

When comparing measured humeral flexion angles, both male and female participants overestimated the target angle of 90°. Males estimated an average of 93.53°, while females estimated 98.75°. Although females tended to overestimate to a greater degree, the difference was not significant ($t(31) = -1.72$, $P = 0.095$) (**Figure 3**). Regarding JPE, the analysis of AE revealed a significant difference between the sexes ($P = 0.003$), with females exhibiting higher AE values than did males (Figure 4). However, no significant sex difference was observed in CE ($P = 0.095$) (**Figure 4**).

To assess the reliability of repeated elbow flexion estimations, the ICC (3,1) was calculated. The overall ICC for all participants was 0.964 (95% CI: 0.928–0.982, $P < 0.001$), indicating excellent test–retest reliability. When analyzed by sex, the ICC for male participants was 0.952 (95% CI: 0.876–0.982, $P < 0.001$), whereas that for females was higher at 0.972 (95% CI: 0.914–0.991, $P < 0.001$).

Table 1. **Participant characteristics (N = 33)**

	Age (years)	Height (cm)	Weight (kg)	Body mass index (kg/m2)
Males (n = 19)	24.0 ± 1.3	174.2 ± 6.8	77.2 ± 14.5	25.4 ± 4.1
Females (n = 14)	22.5 ± 3.1	159.4 ± 8.1	61.4 ± 10.6	24.2 ± 4.2
p value	0.065	<0.001	0.002	0.446

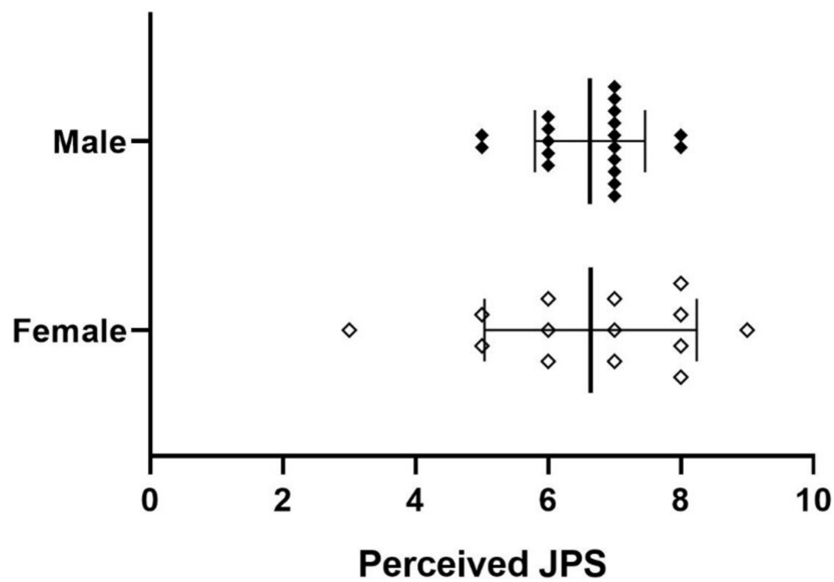

Figure 1. Difference in perceived joint position sense (JPS) between males and females

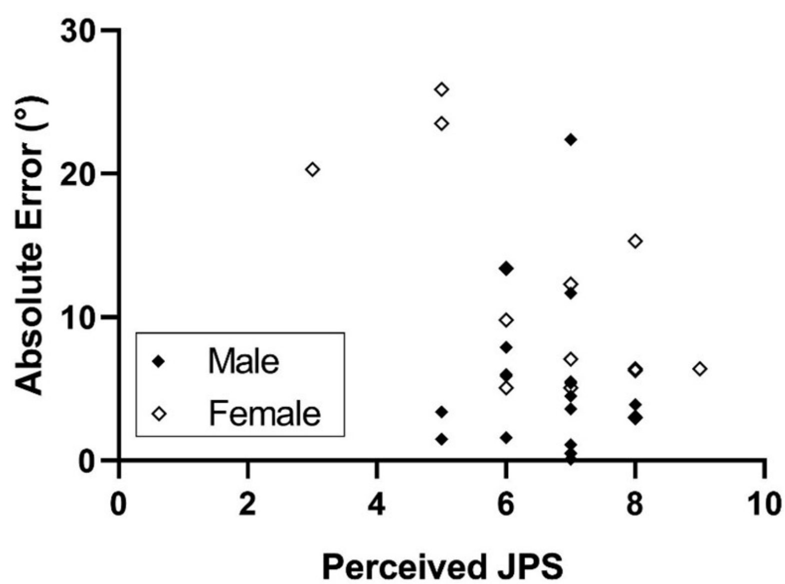

Figure 2. Relationship between perceived joint position sense (JPS) and absolute error

DISCUSSION

The present study examined the relationship between self-perceived JPS and objectively measured JPE. The results revealed a trend indicating that participants with higher JPE values were more likely to rate their proprioceptive ability lower. This suggests that individuals have a level of awareness regarding the accuracy of their joint positioning, even in the absence of external feedback. In other words, proprioception may not function purely as an unconscious sensory process, but may also have a self-awareness component.[22,23] A previous study conducted in our laboratory explored the relationship between self-rated and objectively measured flexibility. The results indicated significant correlations in proximal joints, such as the hip and knee, but not in the ankle.[24] This finding suggests that individuals have a higher perceptual sensitivity for proximal joints than distal ones. Since the current study targeted a proximal joint (i.e., the shoulder-elbow complex), these findings offer a partial explanation of the relationship between perceived and actual joint positioning. Self-perception of physical function is not limited to JPS. Similar phenomena have been observed in another proprioceptive domain—force sense. For instance, participants have been shown to regulate their muscle force output to levels close to the target intensity, even in the absence of visual feedback, especially under submaximal contraction conditions.13 These findings reinforce the notion that individuals retain an internal awareness of their physical capabilities.[25] Such evidence is crucial in interpreting the relationship observed in this study between JPE and self-perceived JPS, because it demonstrates that individuals can regulate movement performance to some extent based on intrinsic awareness, even when sensory feedback is limited. This self-regulatory capacity may be associated with mechanisms such as efference copy, which enables internal prediction of motor output in the absence of external cues.[12,26] In clinical and sports settings, the findings of this study underscore the importance of considering the proprioceptive self-awareness of an individual. Some individuals may not accurately perceive their joint positions, making proprioceptive training with cognitive feedback especially helpful.[27] For example, in rehabilitation settings, failure to accurately perceive joint position may lead to the development of compensatory movements, which could hinder recovery.

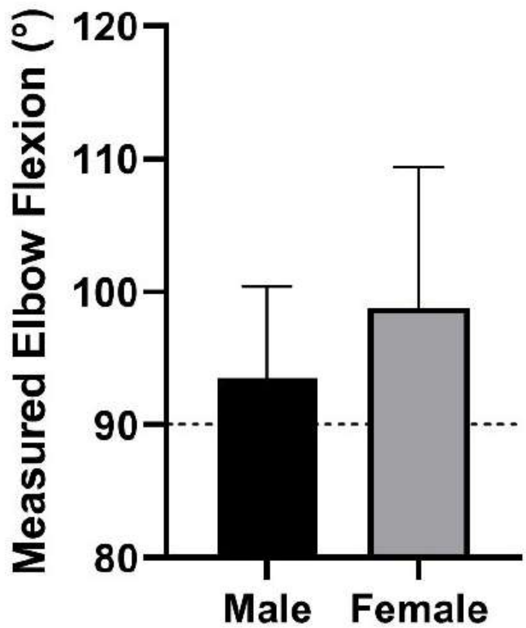

Figure 3. Comparison of the measured elbow flexion angle (°) between males and females
The dashed line represents the target elbow flexion angle of 90°

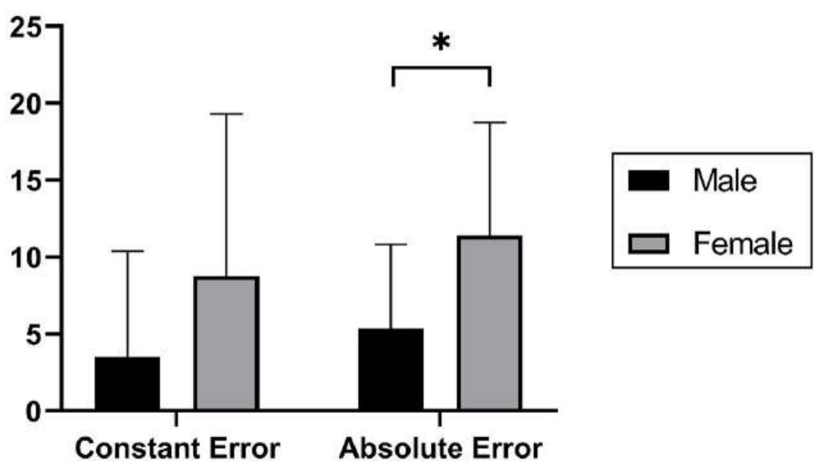

Figure 4. Comparison of the constant and absolute errors between males and females

Therefore, integrating cognitive feedback strategies into JPS training could potentially enhance movement performance and reduce the risk of injury by improving proprioceptive self-awareness.[28] Nonetheless, recognizing the limitations of self-rated proprioceptive assessments is vital. Subjective ratings may not fully capture the complex characteristics of JPS, because such ratings can be influenced by personal experiences, expectations, and beliefs.[29,30] Perceived exertion ratings can reportedly vary significantly depending on whether participants increase or decrease their contraction force during a task, despite maintaining the same physical output.[13] This further emphasizes the need for cautious interpretation of self-rated sensory evaluations.

Regarding the measured joint angles and CE, both male and female participants exhibited a tendency to overestimate the target angle of 90°, with the degree of overestimation being more pronounced in females. Furthermore, the AE was significantly higher in female participants, indicating lower proprioceptive accuracy compared to males. Mixed findings have been reported regarding sex differences in JPS, with some studies showing superior performance in males, others in females, and some reporting no significant differences.[19,31] Many of these studies focused on the lower limbs, where females frequently exhibited lower JPS acuity during joint repositioning tasks.[20,32] Similar tendencies have been observed in the upper limbs. A study examining shoulder joint repositioning reported a consistent overestimation by females at 90° target angles, aligning with the findings of the current study.[33] Several factors may contribute to the observed sex differences in JPS accuracy, including differences in muscle mass and the number of muscle spindles. Recent studies suggest that proprioceptive information transmitted from muscle spindles plays a more decisive role in JPS than inputs from the joint capsule or skin.[34,35] Given that males typically have greater muscle mass, the larger number of muscle spindles may enhance proprioceptive acuity.[36] Similar trends have been observed in force estimation tasks, where males generally exhibit superior performance. Another potential factor is the difference in proximal control capabilities. Studies on the lower limbs have proposed that females may exhibit less neuromuscular control in the trunk and hip regions, which could reduce joint stability, particularly in the knee.[28] Since the shoulder is also a proximal joint, insufficient control in this region could likewise impair proprioceptive accuracy.[37] Lastly, sex-based differences may exist in how sensory signals from various sources, such as visual, tactile, and vestibular inputs, are integrated and processed within the central nervous system.[38] Differences in multisensory integration patterns between males and females may affect both the accuracy and consistency of proprioceptive performance.[15,39,40] Notably, despite their lower proprioceptive accuracy, female participants in this study exhibited a slightly higher reliability across repeated trials, as reflected by higher ICC values. This suggests that while females showed greater deviations from the target angle on individual trials, their performance was more consistent across repetitions. These results imply potential differences in proprioceptive processing strategies between males and females. Future research should explore these differences using refined experimental designs that include sensory feedback manipulation and assessments of neuromuscular control mechanisms.

This study contributes to the field by examining the relationship between self-rated JPS and objectively measured JPE, as well as sex-based differences in upper limb proprioception. However, some limitations must be acknowledged. First, the JPS assessment was limited to a single-joint movement, and more complex, multi-joint movements were not evaluated. Given that daily and sport-specific movements typically involve multi-joint coordination, future research should consider developing more comprehensive assessment protocols that incorporate coordinated movements of the shoulder, elbow, and wrist joints, to better reflect the complexity of upper limb proprioception in real-life functional tasks. Second, the study did not account for additional factors, such as training interventions or fatigue, both of which may influence proprioceptive function. Future studies should also investigate how these factors affect both the accuracy of joint position sense and individuals' ability to consciously evaluate their proprioceptive performance.

CONCLUSION

This study explored the relationship between self-perceived JPS and objectively measured JPE in the upper limb, while analyzing sex-related differences in proprioceptive performance. Participants performed an elbow flexion task, attempting to reach a target angle of 90°, and the discrepancy between the actual and perceived angles was quantified using CE and AE. The analysis revealed that higher JPE was associated with lower self-rated JPS scores, suggesting that JPS is not purely unconscious but may involve a degree of self-awareness. Both male and female participants tended to overestimate the target angle, with the overestimation being more pronounced among females. Additionally, females exhibited significantly larger AEs, indicating lower proprioceptive accuracy compared to that of males. The observed sex differences in JPS accuracy may be attributed to several factors, including differences in muscle mass and muscle spindle density, variations in proximal control capabilities, and disparities in the integration of sensory information within the central nervous system. In summary, the study demonstrated that self-rated JPS at the elbow is aligned with actual proprioceptive performance, and that female participants showed lower proprioceptive accuracy than males. The findings of this study suggest that when applying JPS training in clinical and sports settings, accounting for the proprioceptive self-awareness of an individual, as well as potential sex-based differences in proprioceptive processing may be beneficial. Enhancing self-awareness through cognitive feedback strategies could be a valuable component in rehabilitation and injury prevention programs.

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ETHICAL CLEARANCE

This study was approved by the Institutional Review Board of Woosong University.

CONFLICT OF INTEREST

The author has no conflicts of interest to report.

FUNDING

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AUTHOR CONTRIBUTIONS

WL performed the conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing, visualization, and funding acquisition.

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