



Original Article

A new method for evaluating joint position sense using oral instructions based on body schema

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Abstract. [Purpose] This study investigated the efficacy of our independently developed method for measuring shoulder joint position sense using oral instructions based on body schema (“schema method”) and investigated age-related changes. [Participants and Methods] Forty university students, 19 elderly individuals, and 16 elementary school students were included. Active shoulder abduction was measured in an upright sitting position. Target angles for position sense measurement were 45° of abduction (Target 45) and 90° of abduction (Target 90). The schema method consisted of indicating the target angles through oral instructions alone. The reproduction method and the imitation method were also used to measure angles. Abduction angle, absolute error, and variable error were calculated. [Results] A significant difference in abduction angle at Target 45 was observed between the schema method and the reproduction and imitation methods; no significant differences were observed at Target 90. No significant differences in variable error at Target 90 were observed among the three measurement methods. A significant difference in abduction angle was observed between university students and elderly individuals, and a significant difference in variable error was observed between elementary school students and elderly individuals. [Conclusion] Our body schema-based oral instruction method will be useful for evaluating joint position sense or proprioception.

Key words: Body schema, Proprioception, Shoulder joint

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INTRODUCTION

Joint position sense (JPS), a proprioceptive sense that detects the spatial position of one’s body, is recognized via the input of information from mechanoreceptors in the joints, joint capsules, ligaments, muscles, and tendons to the central nervous system¹⁾. During active movement, muscle spindles and Golgi tendon organs play a particularly important role in JPS²⁾. As JPS is a crucial source of information for maintaining posture and regulating bodily movement, assessment of JPS is also useful for verifying the therapeutic effects of physical therapy³⁾.

The shoulder joint (which, in this article, refers to the glenohumeral joint) is a ball and socket joint with a large range of motion. The stability of the shoulder joint is maintained not only by the bone but also by a static stabilization mechanism (comprising ligaments, a joint capsule, and a labrum) and a dynamic stabilization mechanism (consisting primarily of the muscles surrounding the shoulder). Consequently, shoulder JPS plays a greater role in the regulation of upper limb movement and stability than JPS in other joints. The correlation between shoulder JPS and impairment can be observed in age-related

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shoulder joint disorders, such as frozen shoulder and cuff tears. JPS dysfunction conceivably plays a role in the development of these disorders. Two studies showed that JPS in shoulders with rotator cuff tears and in frozen shoulders is significantly decreased compared to that in healthy shoulders^{4, 5}); another study reported that shoulder JPS in shoulder instability is significantly decreased, but recovers 5 years after surgical repair⁶). Thus, the measurement of shoulder JPS is important in assessing and treating the shoulder joint in clinical practice.

JPS can be measured in passive or active movement. Measurement in passive movement enables confirmation of proprioceptor activity elicited by the extension of the ligaments and joint capsule, whereas measurement in active movement primarily enables confirmation of muscle spindle activity^{2, 7}). Therefore, measurements of JPS differ based on the use of active versus passive movement, one of which must be chosen as necessity dictates.

There are generally two methods used to measure JPS. The first method involves memorizing the target joint position and reproducing it after returning the upper limb to the initial position (hereafter, the “reproduction method”⁸). The second method involves maintaining the measured upper limb at the target joint position and imitating that position using the opposite upper limb (hereafter, the “imitation method”⁹). These methods are chosen based on the disorder in question and measurement site; however, caution is required when using these methods in clinical practice because of the effect of memorization capacity¹⁰ and deciding which side to measure.

Therefore, we devised a simpler method for measuring JPS that is also clinically applicable. This method uses the patient’s body schema as the target angle. Body schema is an image formed by the integration of multiple senses such as proprioception and touch pressure that exists in the interaction between the positional relationships of the body and the environment¹¹. We thought that JPS could be evaluated by performing the target angle only by oral indication and calculating the standard error of multiple measurements.

The present study aimed to examine our body schema-based oral indication method will be useful for evaluating JPS or proprioception. After that, we used the schema method to investigate age-related changes in shoulder JPS measurements.

PARTICIPANTS AND METHODS

The present study was performed with three groups of participants. Group 1 consisted of 40 university students (hereafter, “youth”) with no past history of evident shoulder disorders who were not actively engaged in sports or other activities involving vigorous use of the upper limbs. The 40 participants in this group, all of whom were aged 20 years, consisted of 22 males and 18 females.

Group 2 consisted of 19 elderly individuals (hereafter, “elderly”) with no current evident shoulder disorders. This group comprised 5 males and 14 females with a mean age of 72.2 ± 5.4 years. Individuals with past histories of shoulder disorders were allowed to participate, provided that they did not exhibit evident muscle weakness or limited range of motion at the time of the study. Group 3 consisted of 16 elementary school students (hereafter, “juveniles”) with no past history of evident shoulder disorders. This group consisted of 15 males and 1 females with a mean age of 9.3 ± 0.5 years. In the three groups, individuals with current symptoms such as shoulder pain were excluded from the study. Prior to measurement, all participants were asked which hand was their dominant hand; the side of each participant’s dominant hand was used for measurement. Three groups were collected to investigate the age relationship to JPS.

Measurements were performed with the participants in an upright sitting position, the upper limb in a forearm neutral position, the elbow in an extended position, and the eyes closed. Movement consisted of shoulder abduction in the frontal plane; measurement was performed in active motion. Prior to measurement, participants received sufficient explanation about the nature of measurements and the direction of movement in order to prevent compensatory movement of the scapula and trunk.

During measurement, the participants’ shoulder joints were photographed from the dorsal side using a digital camera. To minimize the effect of digital camera distortion, the camera was placed 3 m away from the participant, with the height of the camera adjusted to the height of the participant’s shoulder joint; photographs were taken such that the shoulder joint was at the center of the image. The zoom was fixed at maximum wide angle.

Markers were attached to the inferior border of the posterior aspect of the acromion and the lateral epicondyle of the humerus. The angle formed by the line connecting the inferior border of the posterior aspect of the acromion to the lateral epicondyle and the vertical line descending from the inferior border of the posterior aspect of the acromion was defined as the shoulder abduction angle. Angles were calculated from digital camera photographs using ImageJ (NIH, Bethesda, MD, USA)¹².

Shoulder JPS was measured using our independently developed schema method and the conventional reproduction and imitation methods. Procedures for measurement with each method are described below.

Schema method: In the initial position, the upper limb hung downward. The examiner indicated the target position via oral instruction. When the target angle was 90° shoulder abduction, the examiner said the following: “Please raise your arm so that it is horizontal and your shoulder is at a 90° angle.” When the target angle was 45° shoulder abduction, the examiner said the following: “The position of your shoulder with your arm raised horizontally is a 90° angle; based on this position, please raise your arm halfway so that your shoulder is at a 45° angle.” In order to keep oral instruction constant, the number of examiners was one. The participant raised their upper limbs to the indicated position in active motion and maintained that position for 2 s. This maintained position was photographed from the dorsal side using a digital camera. The procedure was

performed for a total of 5 times, with an interval of 10 s between measurements. We confirmed the intra-rater reliability and validity of schema method before this study.

Reproduction method: In the initial position, the upper limb hung downward. To aid the participant in memorizing the target angles, the examiner guided the participant's upper limbs to the target angles with minimal assistance; the participant then maintained that position for 5 s and memorized it. The target angles were determined using a goniometer. The participant then returned their upper limb to the initial position on their own and rested for 5 s. After this rest, the participant was instructed to reproduce the position that they had memorized and to maintain that position for 2 s. This maintained position was photographed from the dorsal side using a digital camera⁸⁾. The procedure was performed for a total of 5 times, with an interval of 10 s between measurements.

Imitation method: In the initial position, the upper limb hung downward. The examiner first guided the participant's measurement-side upper limb to the target angles with minimal assistance; the participant then maintained that position for 2 s. The target angles were determined using a goniometer. With the participant maintaining the position to which their measurement-side upper limb was guided, the examiner instructed the participant to raise their opposite upper limb to the same position. The participant then imitated the target angle using their opposite upper limb; the maintained position was photographed from the dorsal side using a digital camera⁹⁾. The procedure was performed for a total of 5 times, with an interval of 10 s between measurements. In the imitation method, the shoulder abduction angle of the opposite upper limb was used as the measured value.

The target angles were 45° (hereafter, "Target 45") and 90° (hereafter, "Target 90") shoulder abduction. In youth, the order in which Target 45 and Target 90 were measured in the schema, reproduction, and imitation methods was randomized. In elderly and juveniles, the only measurement was Target 90 with the schema method.

First, the mean of the five shoulder abduction angle measurements (hereafter, "ABD") was calculated. Next, absolute error (AE) and variable error (VE) were calculated as indicators of error for assessing shoulder JPS; AE was defined as the absolute value of the difference between the shoulder abduction angle and the target angle, whereas VE was defined as the standard error of the five shoulder abduction measurements¹³⁾.

In the statistical analysis, the normality of the measured values was first confirmed using the Shapiro-Wilk test. For ABD in the schema, reproduction, and imitation methods in youth, for which normality was observed, repeated measures analysis of variance (ANOVA) and post-hoc multiple comparison testing using the Bonferroni correction were performed. For AE and VE in youth, for which normality was not observed, the Friedman test and the Wilcoxon signed-rank test were performed. For ABD among youth, elderly, and juveniles, ANOVA and post-hoc multiple comparison testing using the Bonferroni correction were performed. For AE and VE in youth, elderly, and juveniles, the Kruskal-Wallis test and post-hoc multiple comparison testing using the Steel-Dwass test were performed. For all tests, $p < 0.05$ was considered statistically significant. Statistical analysis was performed using SPSS Statistics 24 (IBM, Tokyo, Japan).

The present study was performed with the approval of the Chubu University Institutional Review Board (approval number: 260116). Participants provided consent based on oral and written explanations of the objective of the study and the measurements involved.

RESULTS

A significant difference in ABD at Target 45 in youth was observed between the schema and reproduction methods and between the schema and imitation methods. No significant differences were observed among measurement methods at Target 90 (Table 1).

A significant difference in AE at Target 45 in youth was observed between the schema and reproduction methods and between the schema and imitation methods. A significant difference at Target 90 was observed between the schema and reproduction methods and between the reproduction and imitation methods. In addition, a significant difference in the schema method was observed between Target 45 and Target 90 (Table 2).

No significant differences in VE at Target 45 or Target 90 in youth were observed among measurement methods. In the schema and imitation methods, a significant difference was observed between Target 45 and Target 90 (Table 2).

In youth, elderly, and juveniles, a significant difference in ABD in the schema method was observed between youth and elderly. No significant differences in AE were observed among the three groups. A significant difference in VE was observed between youth and juveniles and between elderly and juveniles (Table 3).

DISCUSSION

In order to examine whether the schema method is useful for measuring shoulder JPS, we compared its measurements with those of conventional reproduction and imitation methods. First, for ABD at Target 45, measurements in the schema method greatly deviated from 45° compared to those in the reproduction and imitation methods. This result is considered to indicate that expressing a 45° shoulder joint angle based on body schema was difficult. In contrast, at Target 90, measurements in the schema method were similar to those in the conventional methods, conceivably because joint positions such as "the upper limb horizontal in relation to the ground" and "shoulder abduction at a right angle" were easy to mentally picture. Therefore,

Table 1. Shoulder abduction angle by comparison of schema method, reproduction method and imitation method

	Schema	Reproduction	Imitation
Target angle 45°	56.4 ± 8.7	46.5 ± 4.2*	47.2 ± 5.2§
90°	94.4 ± 5.0	92.3 ± 3.6	93.3 ± 4.8

Values are mean ± standard deviation (°).

*Significant difference between schema and reproduction methods (p<0.05).

§Significant difference between schema and imitation methods (p<0.05).

Table 2. Absolute error (AE) and variable error (VE) by comparison of schema method, reproduction method and imitation method

	Schema	Reproduction	Imitation
AE			
Target angle 45°	11.8 ± 8.1*	4.1 ± 2.5§	5.1 ± 3.2†
90°	5.6 ± 3.7	3.8 ± 2.5§	5.2 ± 3.1‡
VE			
Target angle 45°	3.1 ± 1.6*	2.9 ± 1.2	3.4 ± 1.1*
90°	2.3 ± 1.0	2.7 ± 1.3	2.9 ± 1.6

Values are mean ± standard deviation (°).

*Significant difference between Target angle 45° and 90° (p<0.05).

§Significant difference between schema and reproduction methods (p<0.05).

†Schema and imitation methods.

‡Reproduction and imitation methods.

Table 3. Abduction angle (ABD), absolute error (AE), and variable error (VE) by comparison of youth, elderly and juveniles

	Youth (n=40)	Elderly (n=19)	Juveniles (n=16)
ABD	94.4 ± 5.0	89.5 ± 5.9*	91.4 ± 7.5
AE	5.6 ± 3.7	6.3 ± 4.5	7.2 ± 3.1
VE	2.3 ± 1.0	2.6 ± 0.8	4.3 ± 1.7§†

Values are mean ± standard deviation (°).

*Significant difference between youth and elderly (p<0.05).

§Significant difference between youth and juveniles (p<0.05).

†Significant difference between elderly and juveniles (p<0.05).

when using the schema method, the difficulty of the schema must be taken into account when establishing the target angle.

Next, when AE was compared among measurement methods to confirm the degree of error, measurements in the reproduction method were found to have a small AE. In addition, a significant difference in the schema method was observed between Target 45 and Target 90. Therefore, it is possible that recognition of target angles in the schema method depends on the individual because the individual participant's body schema is used as an indicator without memorizing or confirming the target position in advance. Consequently, the reproduction of a memorized target angle, which is the characteristic of the reproduction method, may have been the reason for the small AE in the reproduction method. Based on the above, assessment based on AE was insufficient to confirm the utility of the schema method; therefore, we compared VE, which is an indicator of consistency (or, more accurately, variation) in movement. Consequently, no differences in VE were observed among the three measurement methods. In addition, differences in the degree of extension of the muscles and tendons have been reported to improve the sensitivity of receptors (muscle spindles and Golgi tendon organs)^{2, 14}, whereas the soft tissue is more extended at Target 90 than at Target 45; therefore, VE at Target 90 was small.

There are problems with conventional JPS measurement methods; the reproduction method is affected by memorization capacity¹⁰, whereas in the imitation method, the affected side cannot be properly assessed. In addition, although the reproduction and imitation methods can use deviation from the target angle as an object for assessment (i.e. using AE as a standard), the target angle must be precisely designated, which can be particularly difficult in clinical practice. In the schema method, which was devised so as not to require designation of the target angle, measurement is easier, and body schema and proprioception problems can be assessed by examining ABD and VE, respectively. Based on the above, the schema method

is considered useful for measuring JPS. However, in the schema method, differences in oral instructions may have a major effect on measurements; therefore, it is critical that oral instructions be rigorously standardized.

Measurements of shoulder JPS at Target 90 in three different age groups showed that ABD was low among elderly participants. This result may be due to age-related reduction in proprioceptive sensitivity. In a study by Minagawa et al., two-thirds of women aged ≥ 60 years had asymptomatic rotator cuff tears¹⁵. In the present study, the mean age of elderly participants was 72.2 years; it is highly likely that some of these individuals had asymptomatic rotator cuff tears. In addition, rotator cuff tear patients are reported to demonstrate reduced shoulder JPS⁴, and sensitivity is decreased in the muscle spindles in the muscles constituting the rotator cuff; this may explain why elderly participants showed low ABD.

Next, VE was significantly higher in juveniles than in youth or elderly, thus suggesting major variation in measurements. Nervous system development is reported to be the greatest from ages 8 to 12 years¹⁶. The mean age of juveniles in the present study was 9.3 years, which is precisely when JPS is in the development stage; this may have been the reason for the large variation in measurements. In light of these results, methods of formal instruction in sports may need to be chosen based on the individual's age.

The present study has limitations. First, as measurements were performed in healthy individuals, the association between measurements and medical disorders was not investigated. Secondly, because only three different age groups were included, consecutive age-related changes could not be demonstrated. Finally, shoulder JPS was measured in only one direction of movement (abduction).

Based on the above, the present study demonstrated that the schema method is potentially useful for measuring shoulder JPS. Going forward, it is considered necessary to examine normal values by age group. Since the results are affected by understand of oral instruction, it is necessary to confirm the inter-rater reliability. To further investigate the usefulness of the schema method in diseases of the shoulder.

Conflict of interest

None.

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