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Original Article

Changes in scapular and trunk angles and postural control during right–left hand-behind-back movement

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Abstract. [Purpose] This study aimed to clarify the changes in the scapulothoracic joint and upper trunk angles and postural control during right–left hand-behind-back (HBB) movement. [Participants and Methods] The participants were 20 healthy right-handed men. We measured the HBB movement while standing using a three-dimensional motion capture system. Changes in the internal rotation angle of the scapulothoracic joint, upper trunk rotation angle, and center of pressure (COP) were examined to assess potential right–left differences between the analyzed positions. [Results] As the thumb touched the buttocks, upper trunk contralateral and scapulothoracic joint internal rotations were observed and the COP on the non-HBB side was significantly displaced laterally. There were no right–left differences in the changes between the analyzed positions for all measures. [Conclusion] Upper trunk contralateral rotation and postural control were conducted without right–left differences during HBB movement. These results suggest that upper trunk movement and standing postural control are involved in HBB movement. Therefore, it is useful to focus on the scapulothoracic joint angle, upper trunk rotation angle, and standing postural control during physical therapy evaluation and treatment with HBB movement.
Key words: Hand-behind-back movement, Upper-trunk rotation, Center of pressure

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INTRODUCTION

The movement of the scapula, which is located above the thoracic wall, contributes to upper-extremity motion[1)]. Previous studies have examined body movements during forward-arm elevation. The relationship between scapular and humeral motion was proposed by Codman as the scapulohumeral rhythm[2)], and this rhythm differed between dominant and non-dominant hands[3)]. In addition, thoracic spine movement was observed during arm elevation[4)], and a correlation between scapular and thoracic spine movement was observed during arm elevation[5)].

The hand-behind-back (HBB) movement involves reaching the hand toward the back of the body, and limitations in this movement can significantly impact daily life. The constituent elements associated with the HBB movement are not well understood unlike those for the upper extremity forward elevation. The HBB movement is a combined motion of glenohumeral joint internal rotation, extension, and elbow joint flexion[6)]. During the HBB movement, scapula is rotated internally and downward and also tilted anteriorly[6, 7)]; however, no report has described the trunk movement. We hypothesized that trunk movement would also occur during the HBB movement; however, this theory remains unelucidated.

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In a previous study, the finger-vertebral distance (FVD), which is the distance from the spinous process of the seventh cervical vertebra (C7) to the apex of the thumb, was used to evaluate HBB movement, and the FVD differed between the right and left hands[8]. Furthermore, we anticipated differences in the scapula, and trunk movements between the right and left hands during the HBB movement; however, this hypothesis needs to be evaluated. Moreover, we predict that standing postural control during the HBB movement differs between the right and left hands because the standing posture is asymmetrical. Previous studies showed that lower-leg weight-bearing was asymmetrical in the standing position[9, 10]. Postural control during upper-limb flexion movements has been reported. Unilateral flexion of the upper extremity is accompanied by trunk movement prior to upper limb movement[11], and asymmetrical anticipatory postural adjustment occurs during upper extremity motion while standing[12, 13]. In addition, movement of the center of pressure (COP) in the lateral component occurs during trunk rotation produced by arm movements[14], and unilateral arm movements are associated with an COP backward shift[15]. However, no report has described it in the HBB movement. An understanding of the movement elements in HBB movement can be obtained by assessing postural control and can help in physical therapy evaluation and treatment to improve HBB movement.

Therefore, this study aimed to clarify the internal rotation angle of the scapulothoracic joint and trunk as well as lateral displacement of the COP in postural control during the HBB movement of the right and left hands. We posited that changes in trunk rotation, COP, and internal rotation of the scapulothoracic joint would be observed during the HBB movement. In addition, we hypothesized that the internal rotation angle of the scapulothoracic joint and the trunk rotation angle would be greater in the right, than in the left HBB movement. Moreover, we anticipated that the displacement of the lateral COP on the lower limb on the HBB side would be greater during the right compared to that during the left HBB movement.

PARTICIPANTS AND METHODS

This observational study, which spanned from February to October 2023, recruited 20 healthy right-handed participants via email. A previous study that reported on COP data on postural stability during arm movements in 20 healthy adults[16] was the basis in determining the number of participants for this study. Exclusion criteria encompassed patients with complaints regarding the glenohumeral joint or trunk, a history of glenohumeral joint and upper extremity surgery, or the presence of any neurological diseases. Those unable to perform the HBB movement to the level of the eighth thoracic vertebra (Th8) were also excluded. Participants who had predominantly engaged in sports involving only the right upper limb, such as baseball[17], volleyball[18], or tennis[19] were likewise excluded due to documented right–left differences in the internal rotation angle of the glenohumeral joint. Therefore, inclusion criteria were participants with no complaints regarding the glenohumeral joint or trunk, history of glenohumeral joint or upper extremity surgery, or any neurological diseases. Those who can perform HBB movement to the Th8 level as well as those who were not predominantly engaged in sports involving only the right upper limb were also included (Fig. 1). Written informed consent was obtained from all participants before recruitment into the study. This study was approved by the Showa University Research Ethics Review Board (No. 22-103-B). The mean and standard deviation (SD) of age, height, and weight in this study cohort of 20 participants were 27.6 ± 4.3 years, 170.9 ± 4.3 cm, and 62.3 ± 5.5 kg, respectively.

Before measurement, a physical therapist measured the passive range of motion (ROM) of internal rotation at the humerothoracic joint (at 90° of humerothoracic joint abduction and 90° of elbow-joint flexion), extension, and elbow-joint flexion using a goniometer.

We affixed infrared reflective markers (diameter, 14 mm) to the right and left angulus acromialis (AA), trigonum scapulae (TS), coracoid process (CP), and thumb tip. Furthermore, we affixed markers to the C7, Th8, third lumbar vertebra (L3),

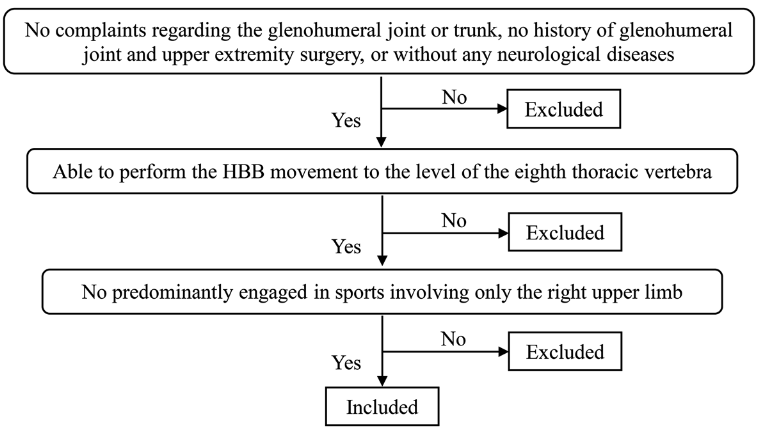

Fig. 1. Inclusion and exclusion criteria.

incisura jugular (IJ), xiphoid process (XP), right and left anterior superior iliac spines (ASIS), posterior superior iliac spine (PSIS), and head of the first and fifth metatarsals. All ROM measurements and marker placement were performed by the same examiner.

We used a three-dimensional motion capture system, VICON NEXUS2 (Vicon Motion System Ltd., Oxford, UK), which uses eight infrared cameras for data capture. The sampling frequency of each camera was set to 100 Hz, and marker coordinate data were captured. Moreover, we used two force plates (AMTI Ltd., Watertown, MA, USA) that were synchronized with VICON to acquire the COP data at a sampling frequency of 1,000 Hz.

The measurement task involved the HBB movements of the right and left hands in the standing position. The participants stood with their feet positioned separately on the right and left sides of the two force plates. The starting position was assumed when the bilateral upper extremities dropped toward the body (dropped-arm position) while gazing forward. The participants were instructed to move their thumb upward from the dropped-arm position to the maximum extent possible along the lateral side of the vertebral spinous process. The participants performed the HBB movement for 2 s to the rhythm of a metronome (120 beats/min). The order of measurement of the right and left hands was randomized, with five trials each.

The local coordinate systems (segments) for the right and left scapula, upper trunk, and pelvis were defined using the VICON Body Builder (ver. 3.6.4, Vicon Motion System Ltd.). The scapular segment was defined from three points −AA, TS, and CP (Fig. 2A), according to the method described by Yoshizaki et al[3]. In the upper-trunk segment, we defined four points: IJ, XP, C7, and Th8 (Fig. 2B) according to previous studies[20]. According to a previous study[21], the pelvic segment was defined from four points: right ASIS, left ASIS, right PSIS, and left PSIS (Fig. 2C).

Scapulothoracic joint angle (angle of the scapula relative to the upper trunk), and upper-trunk angle (angle of the upper trunk relative to the pelvis) were calculated using the Euler angles. The rotational order for calculating the scapulothoracic joint was X-Y-Z, and the angle around the z-axis was the internal rotation angle of the scapulothoracic joint (+ internal rotation). The rotation order of the upper-trunk angle was Z-X-Y, and the angle around the z-axis was the upper-trunk rotation

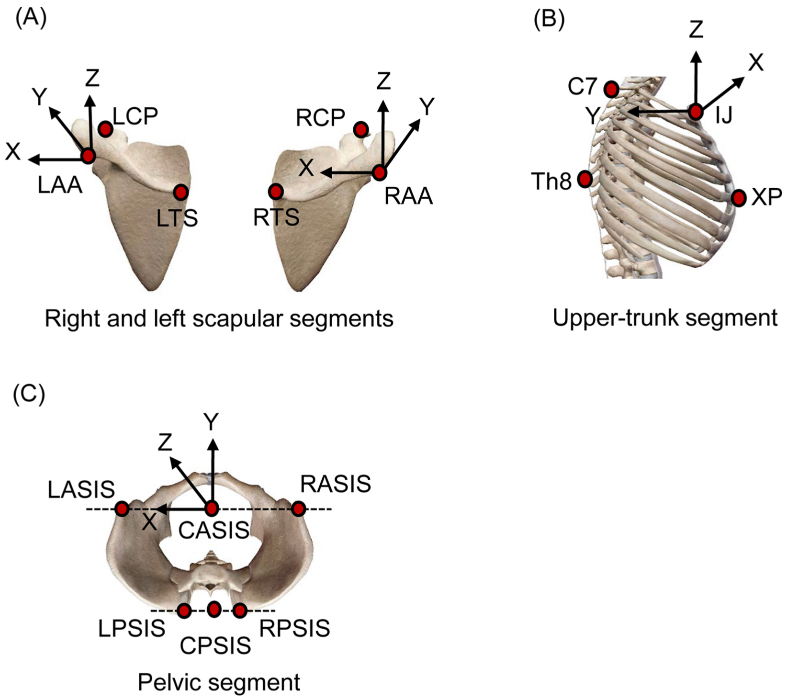

Fig. 2. The segment definitions. (A) The right scapular segment. The origin is the right angulus acromialis (RAA). The vector from the origin to the right trigonum scapulae (RTS) is defined as the X-axis. The cross product of the X-axis and the vector from the origin to the is the Z-axis. The vector perpendicular to the X- and the Z-axes is the Y-axis. The left scapular segment. The origin is the left angulus acromialis (LAA). The vector from the left trigonum scapulae (LTS) to the origin is defined as the X-axis. The cross product of the X-axis and the vector from the origin to the left coracoid process (LCP) is the Z-axis. The vector perpendicular to the X and Z-axes is the Y-axis. (B) Upper-trunk segment. The origin is the incisura jugularis (IJ). The vector from the xiphoid process (XP) to the origin is defined as the Z-axis. The cross product of the Z-axis and vector from the origin to the spinous process of the eighth thoracic vertebra (Th8) is the X-axis. The vector perpendicular to the Z- and the X-axes is the Y-axis. (C) The pelvic segment. The origin is the midpoint of the line connecting the right anterior superior iliac spine (ASIS; RASIS) and the left ASIS (LASIS). The vector from the RASIS to LASIS is defined as the X-axis. The cross product of the vector from the midpoint of the line connecting the right posterior superior iliac spines (PSIS; RPSIS) and the left PSIS (LPSIS) to the origin is the Z-axis. The vector perpendicular to the X- and Z-axes is the Y-axis.

angle (+ contralateral rotation). The order of rotation with the smallest error between the actual and software-calculated angles during scapular and upper trunk movements was determined in a pilot study for each angle and was used when calculating the angle. Therefore, the order of rotation differed between the scapular and upper trunk angles. The noise was filtered from the measured marker data using a low-pass filter (cutoff frequency, 6 Hz; Butterworth Filter).

We extracted the COP with the x-axis displacement in the mediolateral direction (+ lateral direction) from the force plate-derived data. The mediolateral direction was normalized to the length between the first and fifth metatarsal heads at 100%. The noise was filtered from the measured force-plate data using a low-pass filter (cutoff frequency, 15 Hz; Butterworth Filter).

The analyzed positions were extracted from the measured HBB movement, including dropped-arm position (Fig. 3A), with the thumb reaching the PSIS (Fig. 3B), L3 (Fig. 3C), Th8 (Fig. 3D), and maximum (Max) positions (Fig. 3E). The average value of five trials was used in the analysis. The change was calculated by subtracting the analyzed value in the dropped-arm position from that in each of the analyzed positions. We analyzed the amount of change when the value in the dropped-arm position was set to 0.

The Shapiro–Wilk test was performed on all data to examine their normality. A paired t-test was performed to compare the passive ROM of the humerothoracic joint internal rotation, extension, and elbow-joint flexion between the right and left hands. Two-way repeated-measures analysis of variance was performed with the analyzed positions and measurement sides—right and left—as the two factors. Specifically, comparisons were made for the internal rotation angle of the scapulothoracic joint, upper-trunk rotation angle, and COP in the mediolateral directions between the analyzed and measured positions. In cases in which a significant difference in passive ROM of internal rotation at the humerothoracic joint, extension, and elbow joint flexion was observed between the right and left joints, we adjusted for the ROMs as covariates in our analysis of variance to reduce the effect of the right–left difference in ROM on the results of the analysis of variance. When no interaction was observed between the two factors and a main effect was detected for the analyzed positions in the angles, multiple comparisons were performed for the combined right and left values using a post-hoc test. Additionally, multiple comparisons were performed for the combined COP values on the HBB and non-HBB sides. The Tukey–Kramer honestly significant difference and Steel–Dwass tests were used for multiple comparisons when the data did and did not follow a normal distribution, respectively. All statistical analyses were performed using JMP Pro17.0.0. (SAS Institute Japan Co., Ltd., Tokyo, Japan) and the significance level was set at 5%.

RESULTS

A goniometer was used to measure the passive ROMs of internal rotation at the right humerothoracic joint ($p=0.005$; Table 1) and extension ($p=0.018$; Table 1), and they were significantly smaller than those of the left humerothoracic joint.

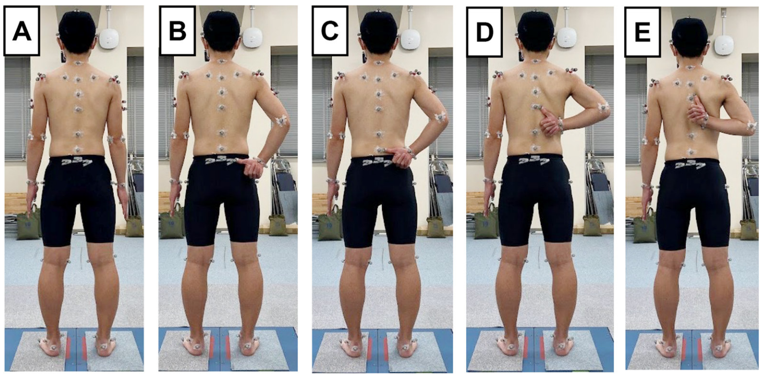

Fig. 3. The analyzed positions. (A) the dropped-arm position, (B) posterior superior iliac spine (PSIS) position, (C) third lumbar vertebra (L3) position, (D) eighth thoracic vertebra (Th8) position, and (E) maximum (Max) position.

Table 1. Passive ROM of internal rotation at the humerothoracic joint, extension, and elbow-joint flexion

	Right	Left
Humerothoracic joint internal rotation (°)	49.8 ± 6.4	57.3 ± 9.2*
Humerothoracic joint extension (°)	46.5 ± 6.5	52.5 ± 8.7*
Elbow joint flexion (°)	146.8 ± 4.1	147.0 ± 4.4

*$p<0.05$ (vs. Right). ROM: range of motion.

No significant difference was observed between the right and left hands in terms of passive ROM of elbow flexion measured with a goniometer (p=0.793; Table 1).

No significant interaction between the analyzed positions and measurement side was observed for changes in internal rotation angle of the scapulothoracic joint (p=0.648) and upper-trunk rotation angle (p=1.000). The change in the angles did not differ between the right and left hands (Table 2). A main effect was observed in the analyzed position. The changes in combined right and left values in the internal rotation angle of the scapulothoracic joint in the PSIS, L3, Th8, and Max positions were significantly greater than those in the dropped-arm position (p<0.001; Table 2). The change in combined right and left values in the internal rotation angle of the scapulothoracic joint at the Th8 position was significantly greater than those in the L3 position (p=0.006; Table 2). The changes in combined right and left values in the upper-trunk rotation angle in the PSIS, L3, and Th8 positions were significantly greater than those in the dropped-arm position (p<0.001; Table 2).

No significant interaction was observed between the analyzed positions and measurement side concerning the change in COP in the mediolateral direction on the lower limb on the HBB (p=0.863) and non-HBB (p=0.986) sides. The change in COP in the mediolateral direction did not differ between the right and left HBB movements. A main effect was observed in the analyzed position, and the change in COP in the mediolateral direction on the lower limb in the non-HBB side in the PSIS (p<0.001; Table 3), L3 (p<0.001; Table 3), Th8 (p<0.001; Table 3), and Max positions (p=0.009; Table 3) was significantly displaced laterally compared with that in the dropped-arm position. No main effect was observed in the lower limbs on the HBB side.

DISCUSSION

This study was conducted to clarify the COP and rotational angles of the scapulothoracic joint and trunk during the HBB movement of the right and left hands. As hypothesized, a change in trunk rotation was observed alongside the internal rotations of the scapulothoracic joint during HBB movement. However, contrary to our hypothesis, the COP lateral displacement of the lower limb was observed on the non-HBB side and not on the HBB side. In addition, no significant difference was observed in the internal rotation angle of the scapulothoracic joint, the trunk rotation angle, or COP between the right and left hands.

The internal rotation angle of the scapulothoracic joint was significantly greater in the PSIS position than that in the dropped-arm position and the Th8 position than in the L3 position. Scapular internal rotation is more pronounced when the thumb reaches the midline of the sacrum behind the back[6]. In the current study, internal rotation of the scapulothoracic joint was observed not only when the thumb reached the sacroiliac joint but also when it reached the thoracic region of the spine. This difference could be attributed to variations in measurement positions. We measured the angle in the standing position, whereas Mallon et al. measured the angle in the prone position. Scapular protraction is greater in the prone position[22], potentially explaining the discrepancy in the scapulothoracic joint angle in the standing posture. We considered that internal rotation of the scapula facilitates orientation of the thumb toward the PSIS position and the upper extremity position that allows the thumb to reach the Th8 position.

Table 2. Changes in internal rotation angle of scapulothoracic joint and upper-trunk rotation angle

		PSIS position	L3 position	Th8 position	Max position
Internal rotation of scapulothoracic joint (°)	Right	6.4 ± 2.2	7.4 ± 2.5	9.0 ± 3.6	9.0 ± 3.7
	Left	6.1 ± 2.3	7.3 ± 2.3	9.7 ± 2.5	10.2 ± 2.8
	Combined	6.2 ± 2.2*	7.3 ± 2.4*	9.3 ± 3.1*, **	9.3 ± 3.3*
Upper-trunk rotation (°)	Right	1.1 ± 0.7	1.4 ± 0.9	1.5 ± 1.1	1.4 ± 1.0
	Left	0.7 ± 1.2	0.8 ± 1.4	1.2 ± 1.8	0.7 ± 2.0
	Combined	0.7 ± 1.2*	0.8 ± 1.4*	1.2 ± 1.8*	0.7 ± 2.0

"Combined" indicates the combined values of the right and left sides; *p<0.05 (vs. dropped-arm position), **p<0.05 (vs. L3 position).
PSIS: posterior superior iliac spine; L3: third lumbar vertebra; Th8: eighth thoracic vertebra; Max: maximum position.

Table 3. Changes in COP in the mediolateral direction

		PSIS position	L3 position	Th8 position	Max position
COP (%)	HBB side	−0.2 ± 1.3	−0.1 ± 1.4	0.1 ± 1.9	0.7 ± 1.9
	non-HBB side	0.7 ± 1.6*	0.9 ± 1.9*	1.2 ± 2.1*	1.2 ± 2.4*

The HBB side comprised the combined value of the right lower limb for right HBB movement and the left lower limb for left HBB movement. The non-HBB side comprised the combined value of the right lower limb for the left HBB movement and the left lower limb for the right HBB movement. *p<0.05 (vs. dropped-arm position).
COP: center of pressure; HBB: hand-behind-back; PSIS: posterior superior iliac spine; L3: third lumbar vertebra; Th8: eighth thoracic vertebra; Max: maximum position.

The upper-trunk rotation angle was significantly greater in the PSIS position than in the dropped-arm position, and the rotation was contralateral to the side of HBB. This study revealed that truncal movement occurs during HBB movement. Notably, the ribs rotate during truncal axial rotation[23)], and the internal rotation angle of the scapulothoracic joint is influenced by the trunk rotation angle[24)] and trunk posture[25)]. Thus, it showed that upper-trunk rotation affects the movement of the scapula, which floats over the ribs. We considered that the contralateral rotation of the upper-trunk contributed to increased internal rotation of the scapulothoracic joint during the HBB movement. A significant difference in change in upper-trunk rotation angle was observed between the dropped-arm and PSIS positions, but not between the dropped-arm and Max positions. We speculate that this is because the variance in the change in upper-trunk rotation angle was large in the Max position, and the variation of angle change was greater in each participant. We initially hypothesized that the upper-trunk and internal rotation angle of the scapular joint, was greater during right HBB movement than that during left HBB movement. However, contrary to our hypothesis, no difference was observed in the upper-trunk rotation angle between the right and left hands. We cannot rule out the possibility that the right–left difference in angle change was not detected because of the small number of participants. We predicted that the smaller ROMs of humerothoracic joint internal rotation and extension in the right than those in the left would be compensated for by scapular internal rotation and trunk rotation in the right HBB movement. We attribute this to the varied motion observed in each participant, such as greater scapular internal rotation and upper-trunk rotation angles, which contributed to the lack of right–left difference. We speculate that varied truncal and scapular movements occurred in each participant, given that the HBB movement is a compound movement.

The COP of the lower limb on the non-HBB side was displaced laterally from the dropped-arm to the PSIS positions. The COP is displaced backward with the forward movement of the upper limb during upper-limb anterior elevation[15)], indicating that COP deviates in the direction opposite to the direction in upper extremity motion. In the current study, we considered that the COP on the non-HBB side was displaced laterally in response to the upper extremity movement in which the thumb reaches the PSIS, while maintaining a standing posture by leaving the center of mass on the lower limb on the non-HBB side. No significant difference was observed in the right and left COPs in the mediolateral direction. We believe that the lack of significant difference is due to the significant variation in COP changes during the HBB movement and the interindividual variations in the COP in the standing posture. In the current study, standing postural control was performed during the HBB movement. The COP changes occurred at the time when significant changes in the internal rotation angle of the scapulothoracic joint and the upper-trunk rotation angle were observed. We presume that the ability to displace the COP in the mediolateral directions is a necessary component of HBB movement.

This study had some limitations. First, all participants were young, healthy, and right-handed. We predicted that the HBB movement in older, left-handed, and female individuals and those with glenohumeral joint disease would differ from that observed in the present study. Second, the participants were instructed to perform the HBB movement along the lateral side of one fingerbreadth of the vertebral spinous process because the markers were placed on the spinous process. The results may differ depending on how the HBB movement is performed. Finally, the analyzed values may have had errors from the actual joint angles due to the rigid-body model and the displacement of the markers on the skin and bone.

During the HBB movement, changes in the upper-trunk rotation angle were observed in addition to those in the internal rotation angles of the scapulothoracic joint. Furthermore, changes in the COP in the mediolateral direction on the lower limb on the non-HBB side indicated the performance of postural control. Therefore, to improve the HBB movement, it is advantageous to focus not only on the glenohumeral and scapulothoracic joints, but also on upper-trunk rotation and standing postural control during physical therapy evaluation and treatment. This study reveals uniformity in measurement items between the right and left hands; However, further studies are needed to elucidate the underlying rationale.

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Conflict of interest

The authors have no conflicts of interest to declare.

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