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Effects of elevation on shoulder joint motion: comparison of dynamic and static conditions

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Background: Although visual examination and palpation are used to assess shoulder motion in clinical practice, there is no consensus on shoulder motion under dynamic and static conditions. This study aimed to compare shoulder joint motion under dynamic and static conditions.
Methods: The dominant arm of 14 healthy adult males was investigated. Electromagnetic sensors attached to the scapular, thorax, and humerus were used to measure three-dimensional shoulder joint motion under dynamic and static elevation conditions and compare scapular upward rotation and glenohumeral joint elevation in different elevation planes and angles.
Results: At 120° of elevation in the scapular and coronal planes, the scapular upward rotation angle was higher in the static condition and the glenohumeral joint elevation angle was higher in the dynamic condition ($P<0.05$). In scapular plane and coronal plane elevation 90°–120°, the angular change in scapular upward rotation was higher in the static condition and the angular change in scapulohumeral joint elevation was higher in the dynamic condition ($P<0.05$). No differences were found in shoulder joint motion in the sagittal plane elevation between the dynamic and static conditions. No interaction effects were found between elevation condition and elevation angle in all elevation planes.
Conclusions: Differences in shoulder joint motion should be noted when assessing shoulder joint motion in different dynamic and static conditions.
Level of evidence: Level III, diagnostic cross-sectional study.

Keywords: Three-dimensional analysis; Shoulder; Scapulohumeral rhythm; Dynamic; Static

INTRODUCTION

Shoulder joint movement in upper limb elevation is achieved through coordinated action of the periarticular muscles, and a scapulohumeral rhythm disruption has been reported in many patients with shoulder joint dysfunction [1-5]. To identify abnormal shoulder motion, it is necessary to understand the characteristics of shoulder joint elevation movements in healthy subjects. Such movements have been shown to be affected by various factors (age [6], sex [7], speed of movement [8], fatigue [9], external loading [10], etc.). Evaluation of shoulder motion in clinical rehabilitation is generally performed by subjective assessment (e.g.,

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visual inspection and palpation). Atypical shoulder rhythms are identified heuristically [11]. Although changes in shoulder motion are associated with pathologies such as shoulder impingement [2,5,12], shoulder rhythms can differ by more than 5° [8-10,13]. Therefore, a difference greater than 5° in shoulder assessment has been the most plausible criterion for reliably detecting changes in shoulder rhythm [14]. Several studies have investigated static arm positions, even though most daily activities involve dynamic tasks rather than static postural maintenance [15,16]. There is a lack of information regarding the rhythms achieved with static positions compared to scapular positions in dynamic movement assessment.

Therefore, research is needed to define normal parameters to characterize more accurately abnormal shoulder features, to improve treatment efficacy, and to consider a variety of treatment approaches. The purpose of this study was to evaluate the effects of test conditions on the shoulder joint using a three-dimensional (3D) motion device. Specifically, the study investigated the effects of static versus dynamic conditions on scapular upward rotation and scapulohumeral joint elevation and measured the interactions in arm height and elevation plane.

METHODS

The Institutional Review Board of Kyushu University of Nursing and Social Welfare approved the study protocol (No. 03-020), and all subjects gave their informed consent for participation in the study and publication of their photographs.

Participants

The dominant arms of 14 healthy adult males with no history of trauma or disability to the shoulder joint were cross-sectionally investigated. Participants volunteered to take part in the study. The mean age was 25.8 ± 3.9 years, mean height 172.8 ± 4.8 cm, mean weight 61.2 ± 7.5 kg, and mean body mass index 20.4 ± 1.9 kg/m^2; and the dominant hand in all cases was the right.

Measurement Procedures

The two motor conditions were dynamic and static elevation of the shoulder joint while seated in a chair. Both conditions were measured in three planes of motion: sagittal, scapular, and coronal (Fig. 1A). The dynamic condition was an automatic exercise, during which the subject was instructed to slowly move the arm beginning at the side in adduction to maximum elevation over a period of three seconds. The subjects were given sufficient practice before the measurement to ensure consistent elevation speed, and the measurements were performed twice. The static condition was to hold the elevated position, and the physical therapist assessed the angle between the vertical line to the floor through the acromion and the long axis of the humerus at 30°, 60°, 90°, and 120° with a goniometer and asked the subjects to hold the angle for five seconds (Fig. 1B). To avoid bias in the order of conditions, subjects were randomized between automatic exercise or elevation and holding, as well as the order of measurement among planes of movement.

For the study, 3D motion analysis was performed during execution of the condition; 3D motion data of the thorax, humerus, and scapula were collected using a LIBERTY electromagnetic tracking system (Polhemus Inc.) at a sampling rate of 120 Hz. The system consisted of a low-frequency electromagnetic transmitter, seven sensors (receivers), a stylus (digitizer), and a system unit. The angular directional accuracy of the system was reported to be 1.3° [10], and the root mean square error due to skin motion artifacts during upper extremity elevation was less than 5° for elevation angles less than 120° [17]. Therefore, in this study, data with shoulder joint elevation angles ≤ 120° were included in the analysis, and comparisons were performed at 30° intervals as reference values. The global coordinate system was established by mounting the transmitter on a wooden frame and aligning it with the cardinal planes of the body. Electromagnetic sensors were mounted on the sternum, above the acromion process, and on the humerus (Fig. 2A). Landmarks on the sternum, humerus, and scapula were palpated and digitized using stylus sensors (digitizer) to construct an anatomical local coordinate system (LCS) (Fig. 2B). These procedures were performed with the subject seated in a chair and arms relaxed at the sides in adduction. The LCS was selected according to the criteria of the International Society of Biomechanics as follows [18]. The C7 spinous process (C7), T8 spinous process (T8), incisura jugularis (IJ), and xiphoid process (XP) were used as thoracic landmarks. The humeral center of rotation (estimated through the rotation method), lateral epicondyle (LE), and medial epicondyle (ME) were used as humeral landmarks, and acromial angle (AA), trigonum spinae (TS), and inferior angle (IA) were used as scapular landmarks. The superior thoracic axis (Yt axis) was defined as the midpoint between T8 and XP to the midpoint between C7 and IJ; the right-facing lateral axis (Zt axis) was defined as perpendicular to the plane defined by IJ, C7, and the midpoint between XP and T8; and the anterior axis (Xt axis) was the cross product of Yt and Zt axes. The humeral longitudinal axis (Yh axis) extends from the midpoint between LE and ME to the scapular center of rotation; the anterior directed axis (Xh axis) is perpendicular to the plane defined by the scapular center of rotation, LE, and ME; and the lateral directed axis (Zh axis) is defined as

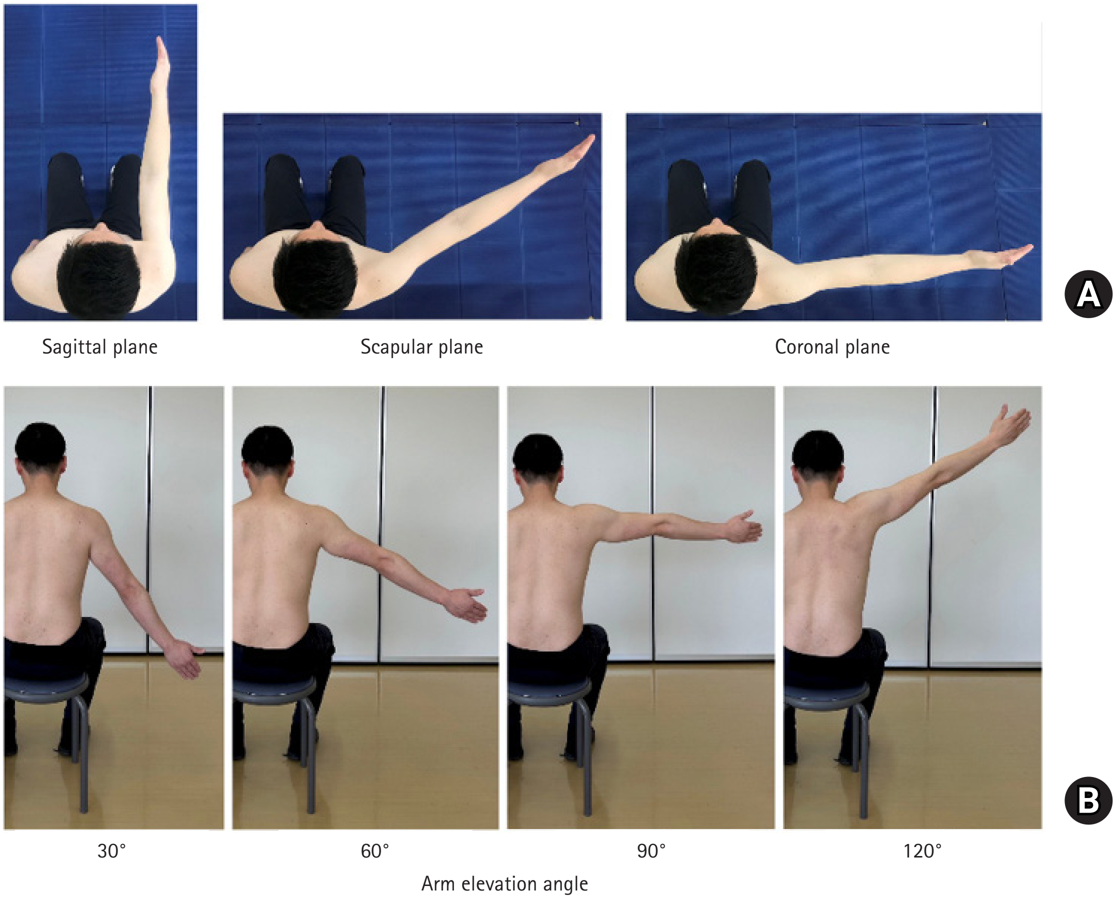

Fig. 1. Setting of elevation plane and elevation angle. (A) Elevation plane. (B) Arm elevation angle under static conditions.

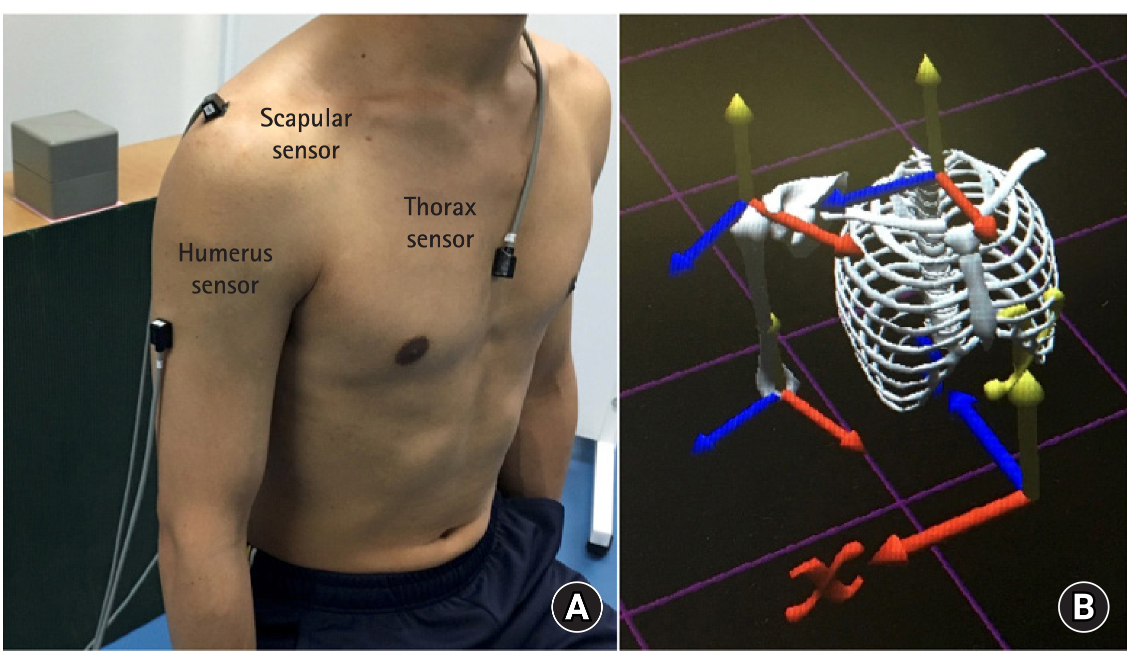

Fig. 2. Magnetic sensor position and construction of an anatomical local coordinate system (LCS) in the electromagnetic tracking system. (A) Magnetic sensors were fixed to the sternum, scapula (acromion), and humerus (in the neutral position) using double-sided tape on the participants' dominant side. (B) The bony landmarks of the thorax, humerus, and scapula were palpated and digitized with the stylus sensor (digitizer) to establish the anatomically-based LCS. The LCS was selected according to the criteria of the International Society of Biomechanics [18].

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the product of Xh and Yh axes. The transverse directional axis (Zs axis) of the scapula extends from TS to AA; the anterior directional axis (Xs axis) is perpendicular to the plane defined by TS, AA, and IA; and the superior directional axis (Ys axis) is the product of the Xs and Zs axes. Scapulothoracic and glenohumeral joint angles were calculated by MotionMonitor ver. 8.43 software (Innovative Sports Training Inc.) in the range of 0° to 120° humeral angle to the rib cage. Arm elevation angle, scapular upward rotation angle, and glenohumeral elevation angle were calculated relative to the thorax (Fig. 3). Rotation of the distal coordinate system was described with respect to the proximal coordinate system using Euler angles, based on the recommendations of the International Society of Biomechanics [18]. The YXZ sequence was used to define scapular motion relative to the thorax. Rotational motion of the scapula was defined in the following sequence: external/internal rotation (around the Ys axis), superior/inferior rotation (around the Xs axis), and anterior/posterior tilt (around the Zs axis). Humeral motion relative to the scapula was determined using the "Y'XY" sequence, where the first rotation defined the angle of humeral elevation, the second defined the angle of humeral elevation, and the third defined internal and external rotation. Humeral motion relative to the thorax was determined using the "Y'XY" sequence as the elevation angle (second rotation). All motion data were smoothed with a low-pass filter at a cutoff frequency of 8 Hz.

IBM SPSS ver. 25.0 (IBM Corp.) was used for statistical analysis. The measurement reproducibility of the 3D motion analysis of the shoulder joint was confirmed using the intraclass correlation coefficient (ICC; 1, 1). The ICC was calculated by measuring the dynamic conditions twice after the sensor was installed. Arm elevation angle in the static condition and the approximate value of the arm elevation angle in the dynamic condition were extracted, and the scapular upward rotation angle and the scapulohumeral joint elevation angle in the two conditions were compared. Two-way analysis of variance and Bonferroni test were used for comparison with a significance level of 5%.

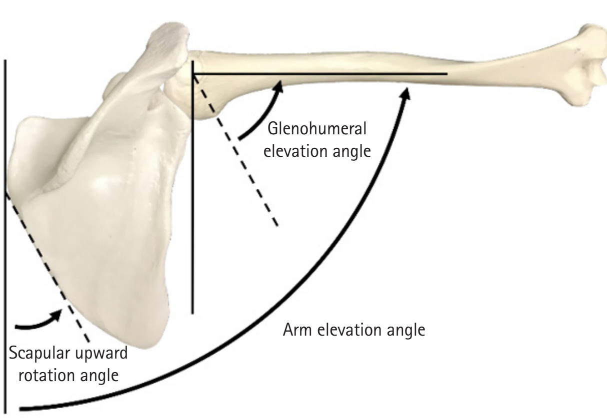

Fig. 3. Measurement parameters.

RESULTS

Reproducibility of Measurements

The ICC values for the angle of scapular upward rotation and of scapulohumeral joint elevation in each elevation plane ranged from 0.974 to 0.994 and were highly reproducible. In order to compare the scapular upward rotation angle and the scapulohumeral joint elevation angle, the approximate arm elevation angles in the static and dynamic conditions were extracted. The differences in upper extremity elevation angles for dynamic versus static elevation were as follows. In the sagittal plane, the values were 0.3°±0.1° at 30°, 0.2°±0.1° at 60°, 0.3°±0.1° at 90°, and 0.2°±0.1° at 120°. In the scapular plane, the values were 0.2°±0.1° at 30°, 0.2°±0.1° at 60°, 0.2°±0.1° at 90°, and 0.1°±0.1° at 120°. In the coronal plane, the values were 0.3°±0.1° at 30°, 0.2°±0.2° at 60°, 0.2°±0.1° at 90°, and 0.2°±0.1° at 120°.

Comparison of Elevation Angle

In sagittal plane elevation, neither the main effect by exercise task nor the interaction effect by elevation angle was observed. In scapular plane elevation, the scapular upward rotation angle (dynamic and static) was 31.6°±5.1° and 36.6° ±5.3° at 120° of elevation and was higher in the static than in the dynamic condition, indicating a main effect ($P=0.016$). In scapular plane elevation, the scapulohumeral joint elevation angle (dynamic and static) was 65.6°±6.8° and 60.0°±5.5° at 120°, higher in the dynamic than in the static condition, indicating a main effect ($P=0.037$). No interaction effect was observed in scapular plane elevation. In coronal plane elevation, the scapular upward rotation angles (dynamic and static) were 32.5°±5.6° and 40.4°±7.9° at 120° of elevation, higher in the static than in the dynamic condition, indicating a main effect ($P=0.001$). In coronal plane elevation, the scapulohumeral joint elevation angle (dynamic and static) was 68.3°±7.6° and 60.2°±4.8° at 120°, higher in the dynamic than in the static condition, indicating a main effect ($P=0.002$). No interaction effect was observed in coronal plane elevation. These results are shown in Fig. 4.

Comparison of Change

In sagittal plane elevation, neither the main effect by exercise condition nor the interaction effect by angle change was observed. The angular change (dynamic and static) of scapular upward rotation in scapular plane elevation was 8.1°±1.5° and 10.1°±2.9° between 90° and 120° of elevation, which was higher

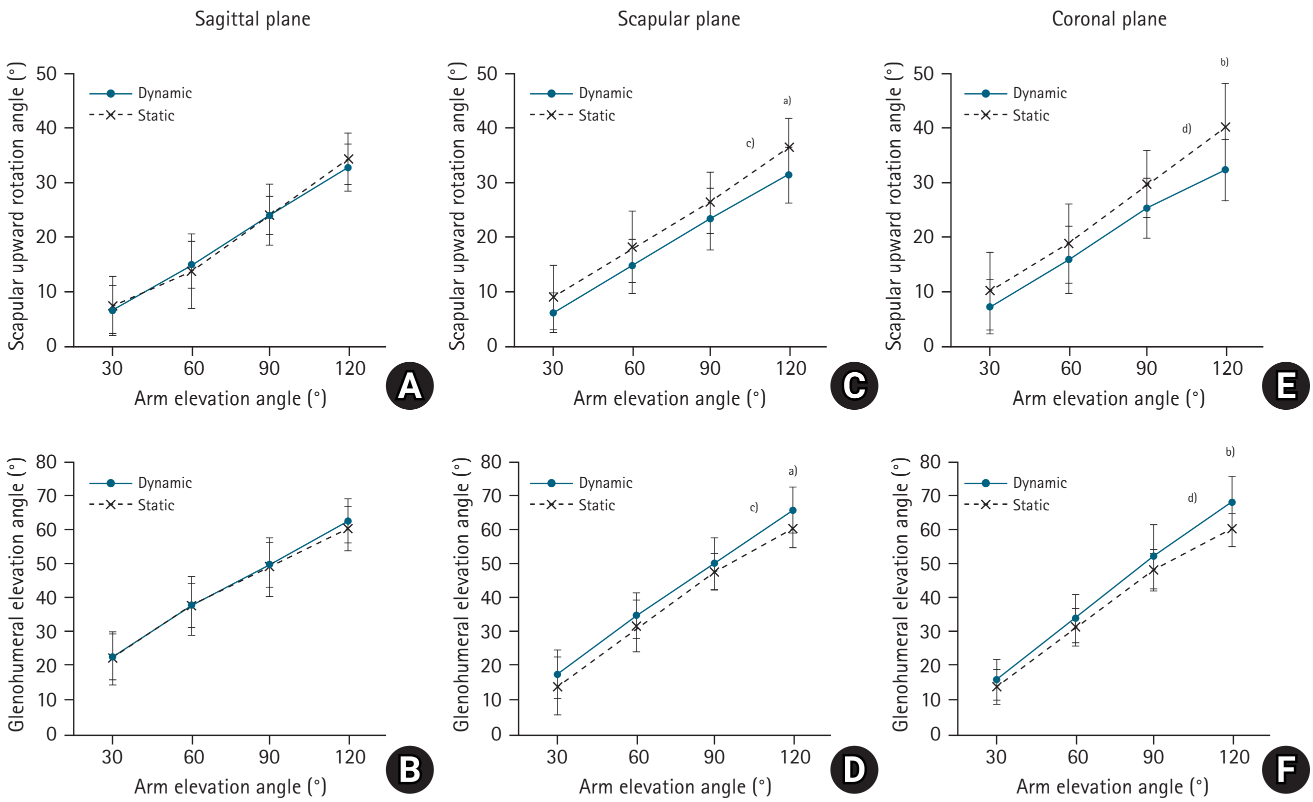

Fig. 4. Motions of dynamic and static conditions during arm elevation. (A) Scapular upward rotation of sagittal plane. (B) Glenohumeral elevation of sagittal plane. (C) Scapular upward rotation of scapular plane. (D) Glenohumeral elevation of scapular plane. (E) Scapular upward rotation of coronal plane. (F) Glenohumeral elevation of coronal plane. Elevation angle: [a]P<0.05, [b]P<0.01; Angular change: [c]P<0.05, [d]P<0.01.

in the static condition than in the dynamic condition, indicating a main effect (P = 0.038). The angular change (dynamic and static) of scapulohumeral joint elevation in scapular plane elevation was 15.6° ± 3.1° and 12.3° ± 3.8° between 90° and 120° of elevation, higher for dynamic than for static condition, indicating a main effect (P = 0.03). No interaction effect was observed in scapular plane elevation. The angular change (dynamic and static) of scapular upward rotation in coronal plane elevation was 6.9° ± 2.2° and 10.5° ± 4.5° between 90° and 120° of elevation, which was higher in the static condition than in the dynamic condition, indicating a main effect (P = 0.008). The angular change (dynamic and static) of scapulohumeral joint elevation in coronal plane elevation was 15.9° ± 3.5° and 11.7° ± 4.6° between 90° and 120° of elevation, higher for dynamic than for static condition, indicating a main effect (P = 0.008). No interaction effect was observed for coronal plane elevation. These results are shown in Fig. 4.

DISCUSSION

Dynamic and static conditions did not differ at any elevation angle or angular change in sagittal plane elevation. At 120° of elevation in scapular and coronal plane elevation, the scapular upward rotation angle was greater in the static condition than in the dynamic condition, and the scapulohumeral joint elevation angle was greater in the dynamic condition than in the static condition. The scapular upward rotation angle was greater in static than in dynamic elevation, and the scapulohumeral joint angle was greater in dynamic than in static elevation for angular changes between 90° and 120° in the scapular and coronal planes. These results indicate that elevation plane and angle affect the scapular upward rotation angle and scapulohumeral joint elevation angle in dynamic and static conditions. In addition, Ludewig et al. [19] investigated the effects of elevation plane and angle on 3D shoulder joint motion and reported that the scapula rotates upward more in abduction than in flexion after 60° of elevation, with further differences as the elevation angle increases. Additionally, van der Helm and Pronk [20] reported that scapular upward rotation was significantly greater in abduction than in flexion, except in the early and final ranges of elevation, based on abduction and flexion shoulder joint motion analysis results. Particularly, the scapular motion has been shown to primarily depend on the hu-

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meral elevation plane. Furthermore, Fayad et al. [21] stated that scapular upward rotation is smaller in sagittal plane than in coronal plane elevation. The present study revealed that scapular and coronal plane elevations showed greater scapular upward rotation in the elevated plane but less in the sagittal plane. This suggests that sagittal plane elevation may have been less affected by dynamic and static conditions. Previous studies have reported that scapular upward rotation during upper extremity elevation is nonlinear, with most of the motion occurring beyond 90° of elevation and increasing most in the final range [19,22]. Scapular upward rotation reduces the external rotation motion of the glenohumeral joint that is required to fully raise the arm [18]. Therefore, scapular upward rotation may have been more pronounced in abduction exercises, which require a higher degree of humeral external rotation. One possible difference between the dynamic and static conditions is the effects of muscle contraction and activity. Graichen et al. [23] used open magnetic resonance imaging to compare active and passive shoulder abduction movements and revealed that the humeral head is more centrally (inferiorly) located on the glenoid, and that muscle activity causes changes in humeral translation at 90°–120° of elevation. Moreover, Ebaugh et al. [12] compared the effects of active and passive movements on shoulder joint scapular plane elevation using a 3D motion analyzer and reported a significantly higher scapular upward rotation in the active condition from 90° to 120°. Price et al. [24] compared scapulohumeral rhythms from 10° to 50° of shoulder joint elevation under active and passive conditions and revealed no differences in active and passive conditions. Therefore, it is inferred that the influence of muscle activity on shoulder joint elevation action is weaker in the early stages of elevation and increases with elevation angle. However, the muscles were active in both conditions because this study was a comparison of dynamic and static conditions. Therefore, not only muscle contraction and muscle activity, but also the mode of muscle contraction may have an influence. McClure et al. [22] investigated scapular 3D movement patterns during dynamic shoulder joint elevation and descent using a direct bone pin method and revealed that the greatest difference in scapular upward rotation during elevation and descent was in the range of approximately 60°–120° of scapular upward rotation. Lee et al. [25] also found greater scapular upward rotation in lowering than in elevation in the entire 30° to 135° range of elevation, and the difference was more pronounced at 90° and higher. Furthermore, a study in which high-speed and low-speed conditions were added to the elevation and lowering movements reported that the scapular upward rotation was significantly higher in the lowering movement than in the elevation movement under both speed conditions [21]. In these reports, the higher values of scapular upward rotation in the descending movement compared to the elevation movement may indicate higher scapular upward rotation during eccentric contraction compared to concentric contraction as a contraction characteristic of the muscle. Furthermore, this difference becomes more pronounced as the angle of elevation increases. The present study compared dynamic and static conditions. Robert-Lachaine et al. [26] investigated the differences between isometric and afferent contractions in shoulder elevation movements under static and dynamic conditions and active and passive conditions. The elevation angles compared included 30°, 60°, 90°, and 120°, similar to the present study. Their results revealed that scapulothoracic joint upward rotation was 4.2° greater in the static condition compared to the dynamic condition. In the present study, scapular upward rotation was higher under static conditions in the scapular and coronal plane elevations, similar to previous studies.

The present study found significant differences in the angles of scapular upward rotation and scapulohumeral joint elevation at 120° of elevation during scapular and coronal plane elevation. However, the difference between dynamic and static elevation at 120° of elevation was 5°–8°. Previous studies focused on slight differences in shoulder joint motion. Differences in scapular upward rotational momentum were only 4°–5°, including shoulder impingement [2,5] and reduced subacromial clearance [27,28]. Therefore, shoulder joint kinematic assessment may be of great clinical significance although the differences are slight. The results of this study indicate that static conditions do not directly reflect dynamic conditions when arm elevation exceeds 90° in the scapular plane or coronal plane elevation. Therefore, it may be more appropriate to use assessment according to motor characteristics (e.g., dynamic conditions such as active movement or static conditions such as holding the elevation) in patients with symptoms beyond 90° of scapular plane or coronal plane elevation.

The study had several limitations. First, the range of elevation was limited to < 120° due to the need for accurate measurement with electromagnetic sensors [17]. Second, the study population included healthy young adults and the application of results to patients with shoulder disorders is unclear. Third, sitting posture and spinal motion may have influenced the data analysis, although the subjects' posture was carefully checked and controlled before and during the experiment. Finally, no electromyographic analysis was performed in this study, and the influence of direct muscle activity is unknown. However, this study used the differences between dynamic and static elevation assessments in evaluating shoulder disorders symptoms that were measured in three elevation planes and four elevation angles by reliable and valid means. These data can be used as a general guesstimate for shoulder joint motion assessment.

CONCLUSIONS

The scapular upward rotation angle and scapulohumeral joint elevation angle, which form the basis for the motion scapulohumeral rhythm assessment, are affected by the elevation plane and angle in dynamic and static assessments. Thus, differences should be noted when assessing shoulder joint motion under different dynamic and static conditions.

NOTES

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Conflict of interest

None.

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Data availability

Contact the corresponding author for data availability.

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