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Scapular kinematics during humeral elevation in adults and children

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Abstract

Background. Appropriate motion of the scapula is important for dynamic positioning of the glenoid during humeral elevation. A number of studies have described the typical scapular kinematics during humeral elevation in adults. However, children and adults may have differences in scapulothoracic musculature and scapular osteology. To our knowledge, no study has been performed examining scapular kinematics in children with either typical or atypical development. Consequently in children the influence of age and development on scapular motion is currently unknown. The aim of this study was to describe and compare the kinematic patterns of the scapula during humeral elevation in children with typical development and healthy adults.

Methods. Fifteen adults, 7 females, 25–37 years of age, and 14 children, 8 females, 4–9 years of age, participated in this study. Kinematic data were collected using a magnetic tracking device. Subjects were asked to elevate their arm in the scapular plane (40° anterior to the frontal plane) in a sequence of three trials.

Findings. Significant differences were seen between the two age groups in the dependent variables. During scapular plane rotation from 25° to 125°, children showed greater upward rotation (43.9° SD 6.39°) than adults (29.1° SD 10.1°). The mean glenohumeral to scapulothoracic ratio in the scapular plane was 2.4:1 for adults, 1.3:1 for children.

Interpretation. This study demonstrates that there are significant differences in scapular kinematic patterns between children and adults. Children have a greater contribution from the scapulothoracic joint, specifically upward rotation toward humeral elevation. From a clinical perspective, these results can be used to help determine the incorporation of stabilization and mobilization of the scapulothoracic joint during exercises for a child with impairment at the shoulder for improving shoulder function.

1. Introduction

The shoulder moves in a complicated manner during elevation, involving all of the joints at the shoulder complex, to facilitate optimal placement of the hand for function. During elevation, the humerus rotates around the scapula at the glenohumeral joint, the scapula rotates around the clavicle at the acromioclavicular joint, and the clavicle around the sternum at the sternoclavicular joint (Schenkman and Cartaya, 1987). During elevation, glenohumeral motion occurs around the stable base of the scapula, with that stability provided by the scapulothoracic muscles (Paine and Voight, 1993). In addition to stabilizing the glenoid, these muscles also dynamically position the scapula for efficient glenohumeral motion (Paine and Voight, 1993). Appropriate

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motion of the scapula is important for this dynamic positioning of the glenoid, therefore, three-dimensional scapular kinematics plays an important role in shoulder motion.

A number of studies have described scapular kinematics during humeral elevation in adults, in both healthy individuals as well as those with shoulder pathologies (McClure et al., 2001; Graichen et al., 2000; Ludewig et al., 1996; Moriwaki, 1992). In adults, abnormal scapular kinematics are believed to contribute to shoulder pain and pathology and it has been theorized that understanding the typical kinematic pattern of the scapula may provide a basis for evaluation of shoulder pathology (Ludewig et al., 1996). Endo et al. (2004) studied the effects of age on scapular positioning in healthy adults from 16 to 73 years of age. However children were not included in that study and the range of humeral elevation at which scapular positions were studied were maximally 90°. Recently Musqueda et al. (2004) published results on functional activities performed by 55 children with brachial plexus injuries and 51 children with normal children. While in that novel study shoulder flexion was measured using the upper extremity model described by Rab et al. (2002), the shoulder motion was simplified as an overall humeral elevation occurring at the shoulder rather than the motion involving the entire shoulder complex. To our knowledge, no study has been performed examining scapular kinematics in children with either typical or atypical development.

Movement skills in children may be influenced by strength, flexibility and muscular endurance and show an improvement from childhood through adolescence (Branta et al., 1984). These improvements suggest that children and adults may have functional differences in both the osteology of the scapula as well as the scapulothoracic musculature, which may influence their scapular kinematic patterns. While Endo et al. (2004) have described the influence of age and development on scapular position in adults, their influence on the typical patterns of scapular motion in children is currently unknown. An examination of the scapular patterns of motion in children with typical development may help with our understanding of the patterns in children with impairments at the shoulder.

The aims of this study were to describe and compare the kinematic patterns of the scapula during humeral elevation, in typically developing children and healthy adults. The specific hypothesis for this study was that the pattern of scapular kinematic variables, scapular upward rotation, posterior tilt and external rotation, as well as clavicular protraction, clavicular retraction and clavicular elevation during humeral elevation would be different between the two age groups, adults and children.

2. Methods

2.1. Subjects

Fifteen adults (mean of 28.8 years, SD 4.3) and 14 children (mean of 6.7 years, SD 1.5 years) participated in this study. To be included, subjects had to have 160° range of active motion of humeral elevation in the scapular plane. Age restrictions were between the ages of 25–45 years for the adults and 4–9 years for the children. Typical development was defined as the children had attained the developmental milestones, according to parents and did not have any diagnosis related to developmental delay. Additionally, only children who were able to follow simple verbal commands were included. The exclusion criteria for both groups were any history of injury or surgery to the shoulder joint complex, scapula, clavicle, upper thorax, upper back and humerus in the past one year and any allergies to adhesive tape.

An initial screen was performed to check for hand dominance and range of motion before beginning the experiment. To improve the ease of participation in children, the dominant upper extremity was used. Hand dominance was tested by giving the subjects a rubber ball and asking them to throw it overhand three times to the researcher, who was standing 10 feet away. The hand that was used to perform at least two of the three trials was determined to be the dominant arm. The range of elevation in the scapular plane of that arm was tested using a goniometer. Of all the subjects screened, only one adult subject did not meet the inclusion criteria for the range. Also all the subjects in this study reported to have had no prior shoulder injuries that had required medical treatment. Also demographic information (height, weight, age and gender) were collected.

The study was reviewed and approved by a University Institutional Review Board. All adult subjects signed a consent form. For the children, parents signed a consent form and children signed an assent form. The male subjects and all children were tested with their trunk bare. Female subjects wore a sports bra or a halter-top so that the scapula was visible and the clothing did not hamper shoulder movements.

2.2. Kinematics

Kinematic data were collected using a magnetic tracking device (Polhemus 3 space® Fastrak, Colchester, VT, USA). This system has four receivers/sensors; three were mounted on the subject and a fourth used to digitize bony landmarks. Sensors were attached to the skin on the spinous process of T3 spine, the lateral arm just below the insertion of the deltoid, and on the flat part of the acromion (Fig. 1). The system also has a global transmitter, which was fitted on a rigid plastic base and aligned with the cardinal planes of the body (Fig. 1). The Polhemus system interfaced with a Pentium computer and Labview software was used to collect data at a 40 Hz sampling rate. A method has been previously developed with this system to non-invasively assess dynamic three-dimensional scapular kinematics in vivo. The validation of this surface mounted technique were made by comparison of measurements made with an additional receiver attached directly to the scapula with bone pins (Karduna et al., 2001).

Once the receivers were set up, the digitization of the humeral, scapular and thoracic skeletal landmarks was performed. The scapular points were digitized twice, to improve reliability. The process of digitization facilitated transformation of the sensor data to local anatomically based coordinate systems. The coordinate axes and the bony landmarks from which they were derived have been previously described (Karduna et al., 2000).

The use of Euler angles, representing three sequential rotations about the anatomic axes is a common method for describing three-dimensional joint kinematics (Woltring, 1991). Motion of the scapula with respect to the thorax was described based on the Euler rotation sequence of external rotation, upward rotation, and posterior tilt (Karduna et al., 2000). The humeral rotations were represented using Euler rotation sequence of plane of elevation, humeral elevation and internal and external rotation (An et al., 1991). The clavicular angles represent two degrees of freedom of position of the scapula with respect to the thorax: elevation and protraction/retraction. Clavicular plane motions of protraction and retraction were defined as the anterior and posterior motions respectively of the clavicle with respect to the sternum at the sternoclavicular joint. The common clinically described motions of shoulder protraction and retraction would include anterior and posterior clavicular motions at the sternoclavicular joint

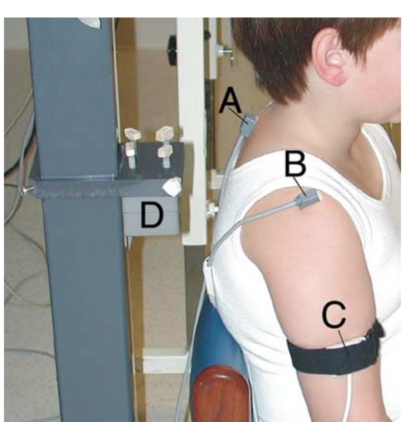

Fig. 1. Experimental set-up. (A) Sensor over thoracic-3rd spinous process; (B) sensor over flat segment of the acromion; (C) sensor on humerus using arm band; and (D) the global transmitter.

along with the scapular rotations at the acromioclavicular joint and scapular translation along the thoracic wall. The clavicular angles were not measured directly but calculated from the position of the sternal notch and the acromioclavicular joint, tracked by the thoracic and scapular sensors respectively.

2.3. Experimental protocol

During testing, the subjects were asked to stand looking straight ahead with feet at a comfortable width apart. The toes were on a line on the floor aligned with the global transmitter immediately behind them at mid-thoracic level. Subjects were asked to elevate their arm in the scapular plane (40° anterior to the frontal plane) with the elbow extended and forearm neutral. The subjects glided their arms along a plastic pipe in the scapular plane and performed a sequence of three trials of humeral elevation.

The movements were demonstrated by the researcher and all the subjects practiced them to enhance their ability to lift their arm to a count of four. Verbal feedback was provided and timing among all the subjects was kept consistent with the same researcher counting to four. Additionally two of the youngest children required visual feedback, with the researcher performing the motion along with them during data collection.

2.4. Data reduction and analysis

For each repetition of humeral elevation, data at 5° increments were calculated by linear interpolation, with the primary humeral rotation serving as the independent variable. These data were averaged over the three repetitions of humeral elevation for each subject. The maximum range of humeral elevation (25°–125°) that was common among all the subjects was selected for analysis. While the adults did reach higher values of humeral elevation, the range selected was the range that all the children had completed. The data for each variable were examined with the scapula moving with respect to the thorax and averaged across the subjects in each age group within the common range of 25°–125° of humeral elevation. The data were divided into three phases of humeral elevation, phase I (25°–60°), phase II (60°–90°), phase III (90°–125°), for both the age groups. The angles of upward rotation, external rotation, posterior tilting of the scapula and clavicular rotation angles of plane and elevation (Fig. 2) were calculated in each of the three phases of humeral elevation. A mixed analysis of variance (ANOVA) with one between subject factor (age: children and adults) and one within subject factor (phase of movement: 25°–60°, 60°–90°, 90°–125°) was used for each of the three scapular variables and two clavicular variables. Also, the dependent variables at the resting position as well as at 25° of elevation were

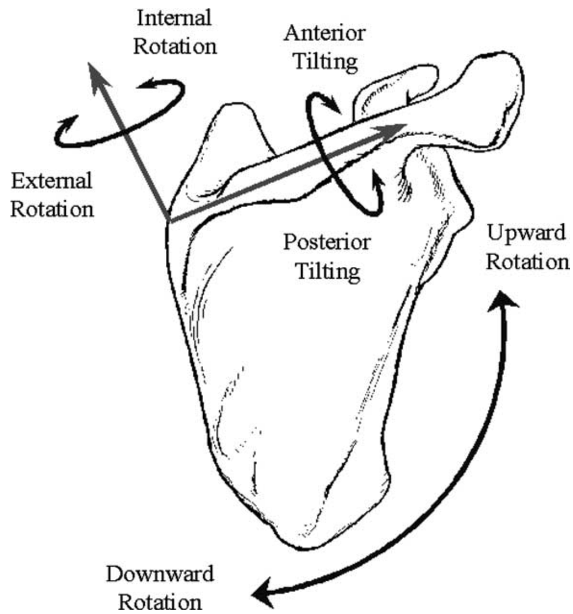

Fig. 2. Scapular variables of posterior tilt, upward rotation and external rotation.

evaluated for differences between the two groups. In addition the amount of scapular upward rotation for the overall range from 25° to 125° was compared between the two age groups. The glenohumeral (gh): scapulothoracic (st) ratio was also derived from the upward rotation of the scapula and the total humeral elevation angles. An alpha level of 0.05 was set for all statistical analysis.

3. Results

During scapular plane elevation the adults and children demonstrated a pattern of increasing upward rotation, increasing posterior tilt, clavicular retraction and clavicular elevation (Figs. 3 and 4). In addition over the range from 25° to 125° the adults demonstrated decreasing external rotation while the children had increasing external rotation. Significant differences were found between the two age groups in upward rotation at rest, at 25° of humeral elevation, in phase I (from 25° to 60°) and phase II (from 60° to 90°) ($P < 0.05$) (Fig. 3). Significant differences were also seen in posterior tilt in phase II (from 60° to 90°) and in external rotation in phases II (from 60° to 90°) and III (from 90° to 125°) ($P < 0.05$) (Fig. 3). For clavicular rotations, differences between the adults and children were seen in clavicular plane retraction in phases I (from 25° to 60°), II (from 60° to 90°) and III (from 90° to 125°), in clavicular elevation at rest, 25°, phases I (from 25° to 60°) and II (from 60° to 90°) ($P < 0.05$) (Fig. 4). Significant differences were also seen in the total amount of upward rotation from 25° to 125° between the 2 age groups ($P < 0.05$). The complete range of average upward rotation seen in children (43.9° SD 6.4°) was higher than that seen in adults (29.1° SD 10.1°). The glenohumeral to scapulothoracic (gh:st) ratios between 25° and 125° of humeral elevation was 2.4:1 for adults and 1.3:1 for children. In phase II (from 60° to 90°) children

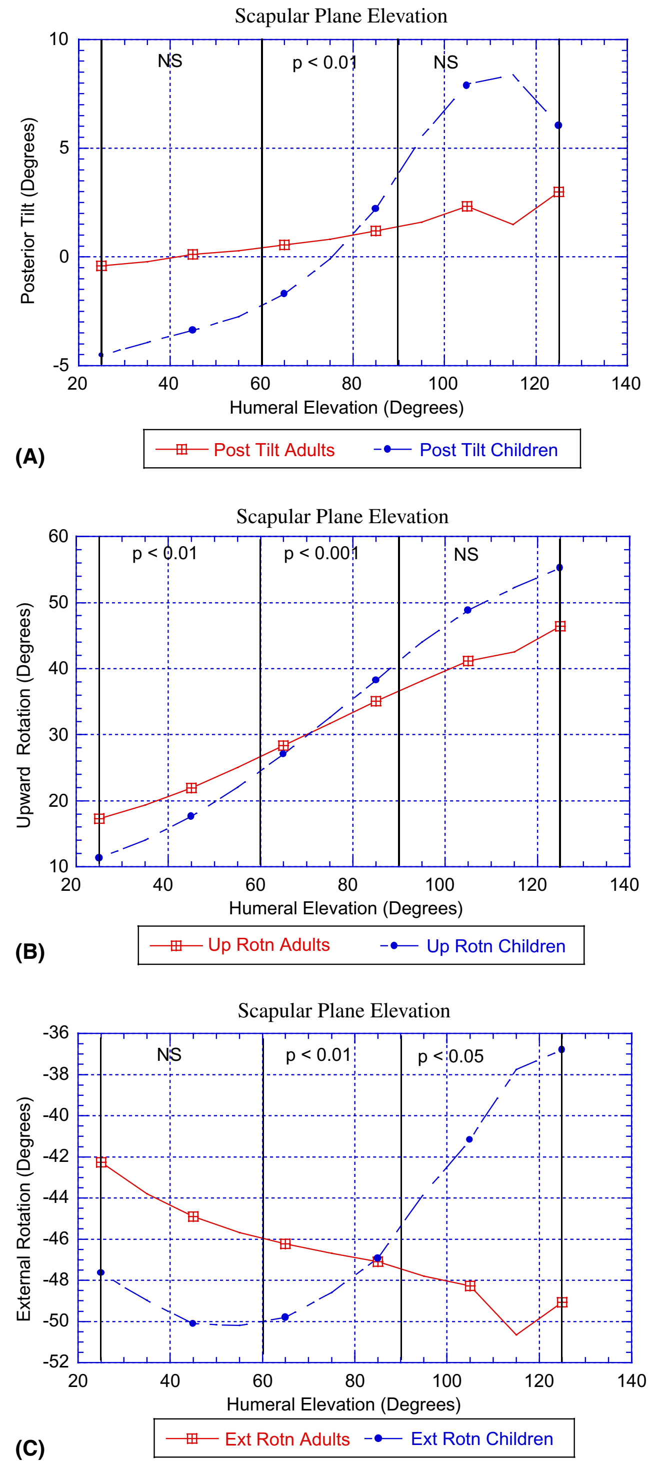

Fig. 3. Scapular rotations: (A) posterior tilting, (B) upward rotation, and (C) external rotation. (NS and P values in the figure represent the results of ANOVA comparisons in the three phases.)

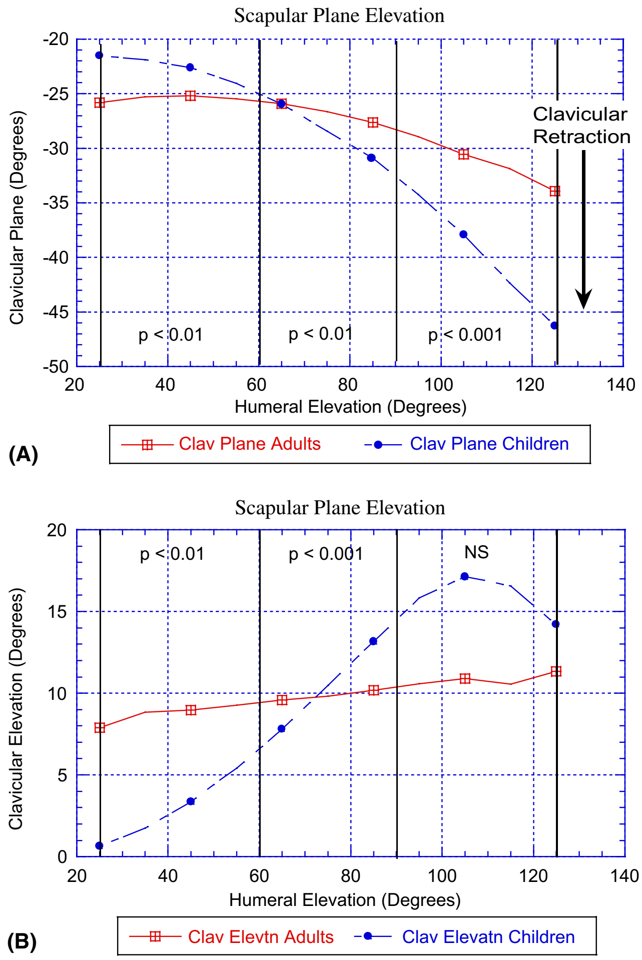

Fig. 4. Clavicular rotations: (A) retraction and (B) elevation (NS and *P* values in the figure represent the results of ANOVA comparisons in the three phases).

demonstrated an average gh:st ratio of 0.8:1, while the adults had a ratio of 2:1 and in phase III (from 90° to 125°) children had an average ratio of 1.5:1 while adults had a ratio of 2.6:1.

4. Discussion

The results of the present study suggest that there are some differences in scapular kinematics between adults and children during scapular plane elevation. The children showed some similarity to typical patterns of scapular motion previously seen in adults (McClure et al., 2001). Children appear to have more upward rotation at the scapular thoracic joint in humeral elevation. The overall gh:st ratio in children (1.3:1) was lower than previous findings in adults while that in adults (2.4:1) in this study was higher (Inman et al., 1944; Poppen and Walker, 1976; McClure et al., 2001). There were also differences seen in the gh:st ratio in the different phases of humeral elevation from 25° to 125°. The gh:st ratio has been shown to be influenced by muscular strengthening (Wang et al., 1999) as well as fatigue (McQuade et al., 1995). There might be inherent differences in muscular strength between children and adults, which might influence scapular motion. It is possible that the adults might have demonstrated different overall gh:st ratios if data were included from higher degrees of elevation. Also, the gh:st ratios in this study were derived from the scapular component and the total humeral elevation angles, which is a simplification of the humeral elevation into a planar motion.

The resting positions of the scapula and the clavicle were different between adults and children. There were significant differences seen in the variables of upward rotation, external rotation and clavicular elevation in the resting position. The precise mechanisms controlling scapular motion are not well understood (McClure et al., 2001) and the resting position might influence muscle lengths and scapular motion. Also, these different resting positions might be due to muscular and age related development. Branta et al. (1984) discuss consistent improvement in movement efficiency and skills seen in children in both upper and lower extremity movement up through adolescence. They comment on the influence of strength, flexibility and muscular endurance on improvement of skills. The scapular musculature at the scapulothoracic joint helps to stabilize the scapula on the thoracic wall such that as elevation occurs the stabilized scapula moves along the thoracic wall and the glenoid is stable throughout to facilitate glenohumeral motion (Paine and Voight, 1993). This stability and mobility of the scapula is dependent on the scapulothoracic muscles. Muscle and strength development through adolescence might influence scapular stabilization, which may affect scapular motion. Endo et al. (2004) have detected decreases in both scapular upward rotation and posterior tilt occurring in adults with age suggesting possible predispositions toward shoulder impingement. In children age related changes of scapular positioning and dynamic patterns are unknown and considering the development and muscular changes occurring in children through adolescence one might expect some change in the positioning of the scapula with development.

The model used in this study of attaching the scapular sensor directly on the skin with double-sided tape was previously validated by comparison with sensors on the scapular spine bone pins (Karduna et al., 2001). They found that the motion detected by the non-invasive method was similar to the invasive method, especially for motion up till around 120°. The root mean square error increases from 120° to 125° were less than 1° and increased mainly beyond 125°. The surface data from that study was examined to provide a basis for comparison with the present study. The children showed a similar pattern of posterior tilt as was seen in the adults in that study. However, the children showed a small anterior tilt at the end of the range, which is different from what is believed to be the typical pattern in adults, but this difference seen was not statistically significant. The posterior tilt motion is believed to be functionally important to allow for unhindered motion of the humeral head and the rotator cuff tendons under the anterior aspect of the acromion during humeral elevation (McClure et al., 2001). Based on data comparison from Karduna et al. (2001), the total amount of posterior tilt seen from the range of 25° to 125° was 10.6°, which was the same as that seen in the children in our study (10.6°), but was higher than that seen in the adult group (3.4°). The posterior tilt the adults had from 125° to 140° of humeral elevation was 5.2°. It would appear that there is an increase in posterior tilt seen at the end ranges, the exclusion of which might account for the reduction in total posterior tilt seen in this study.

The external rotation pattern between the adults and children was seen to be different with the adults showing internal rotation (6.8°) and children showing external rotation (10.8°). Based on data from Karduna et al. (2001) the subjects showed 2° of external rotation from 25° to 125° of humeral elevation. However the subjects in that study showed a total external rotation of 14° from 15° to 140°, most of the external rotation seen in the end ranges. In addition those subjects had bone pins in their scapulas during the humeral elevation motions and while the skin tension errors on the bone pin were very low, it might not completely represent the scapular patterns without the pins present. The subjects in our study glided their arms along a pipe, since it was important to maintain their arms in the scapular plane and it was difficult to achieve this in children without some feedback. It is certainly possible that using that gliding motion might have indirectly restricted the freedom in external rotation of the scapula. The external rotation pattern is believed to be typical in adults, though there have been studies that have reported internal rotation (Johnson et al., 1993). The subjects with impingement have also showed an internal rotation (medial) rotation of the scapula (Ludewig and Cook, 2000). The clinical significance of the typical external rotation pattern is not clear and inherent variability might be present in the internal/external rotation pattern.

The clavicle retracted consistently in both adults and children as is seen in typical patterns reported in literature (McClure et al., 2001). The amount of clavicular retraction from data from Karduna et al. (2001) was 17°, still higher than that seen in our study in adults (8.1°) and less than that seen in the children (24.7°). The subjects in this study showed maximal amount of clavicular plane retraction in the range from 90° to 125°. The adults showed 4.3° of clavicular retraction from 125° to 140° of humeral elevation. The scapular internal rotation seen might have restricted the amount of clavicular retraction seen. Also, the velocity of motion was controlled and changing the velocity might have slightly different results on clavicular retraction. The children might use the increased retraction to help with scapular stabilization. There was a large difference in clavicular elevation between the adults and children. The adults in our study showed 3.5° of elevation during scapular plane humeral elevation. This was different from the 10° calculated from Karduna et al. (2001). The children in our study showed 13° of clavicular elevation. Clavicular elevation would seem to contribute toward total humeral elevation along with glenohumeral elevation and scapular upward rotation. It is possible that these three motions work in a complex manner to compensate for or compliment each other. The adults in our study did show a slightly higher contribution from the glenohumeral joint (2.4:1) and this might explain a reduction in the clavicular elevation. Most of the clavicular elevation occurred by around 90°, which was similar to the findings of Inman et al. (1944). However based on the data from Karduna et al. (2001) the clavicular elevation seems to consistently increase with 6° before 90° of humeral elevation and 4° up till 140° of elevation. The typical pattern of clavicular elevation in the different phases of elevation is unclear and the children might show a greater contribution by clavicular elevation up to 90° of humeral elevation. This could be due to increased activity of the upper trapezius during initiation of humeral elevation corresponding with clavicular and scapular elevation.

The results of this study provide therapists and other clinicians working with children with impairments at the shoulder with some understanding of scapular kinematics seen in children with typical development. Clinically the scapulothoracic joint should be evaluated in children following shoulder injury or significant weakness of the shoulder. Both the stability and mobility at the scapulothoracic joint would need to be considered. While scapular stabilization exercises maybe useful in some diagnostic groups such as those with brachial plexus injuries, the use of scapular mobility might help in overall humeral elevation and functional gains. The larger contribution seen by the scapular upward rotation might help therapists to concentrate on exercises aimed at addressing upward rotation in children with impairments at the shoulder complex. Improved stability at the scapulothoracic joint might improve contribution toward humeral elevation from the glenohumeral joint. The upward rotation in the scapular plane seems to be functional and exercises working at an impairment level by incorporating the scapulothoracic joint may prove to be more functionally useful for the child. Also, the results for the adults showed patterns different from the patterns seen typically which might illustrate inherent variability present in these variables.

There are several methodological limitations in this study that need to be acknowledged. Skin based markers were used to measure the movement of the bones.

Although we have previously validated our measurements of scapular kinematics, there is still some inherent error associated with this technique in studying scapular kinematics at higher ranges beyond 125°. The data set analyzed in this study used a normalized range, 25°–125°, achieved by most of the subjects. This reduction of data has omitted the patterns seen beyond 125° of elevation. More accurate non-invasive methods are required which can track scapular motion over the entire range of humeral elevation. Also, the starting and end positions among most of the subjects were very variable; this reduced the range common to all the subjects. The children in this study were young, between 4 and 9 years of age and with muscular development taking place in children there might be differences seen in the older children. Also, there might be gender differences that were not addressed in this study.

The scapular kinematics in children with typical development may provide some understanding of the kinematics in children with impairment. Shoulder and scapular motion is frequently impaired in children with brachial plexus injuries and in children with spinal cord injuries and further research in these children would prove to be very useful in improving our understanding as well as facilitating examination and intervention for the impairment. Also, EMG analysis of the scapulothoracic muscles in children might provide more insight into the scapulothoracic musculature. Research focusing on gender differences between children at different ages would provide insights into the changes occurring in the scapular kinematics across childhood.

5. Conclusion

This study shows that there are some differences seen between children and adults in scapular kinematics during humeral elevation. The main result was that children have a greater contribution from the scapulothoracic joint, specifically upward rotation during humeral elevation. The clinical importance of these results is that incorporation of the scapulothoracic joint, focusing on both stabilization and mobilization during exercises for children with impairments at the shoulder may assist in improving shoulder function.

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