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Original Article

Enhancing Shoulder External Rotator Electromyography Activity During Sitting External Rotation Exercise: The Impact of Biofeedback Training

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Background: The external rotation (ER) exercise in performed at a 90° abduction of the shoulder joint is an effective to strengthen the infraspinatus. However, failure of the humeral head to control axial rotation during exercise can be increased the posterior deltoid over activity. Biofeedback training is an effective method of promoting motor learning and control it could look forward to activate the infraspinatus selectively by controlling the humeral head during exercise.

Objects: The aim of this study was investigated that whether biofeedback for axial rotation was effective to activate selectively the infraspinatus during ER exercise.

Methods: The 15 healthy males participated, and all subjects performed both ER exercise in a sitting position with shoulder abducted 90° under conditions with and without axial rotation biofeedback. Exercise was performed in a range of 90° ER, divided into three phases: concentric, isometric, and eccentric. The infraspinatus and posterior deltoid muscle activity were observed using surface electromyography.

Results: Both infraspinatus activity ($p < 0.01$) and infraspinatus to posterior deltoid activity ratio ($p = 0.01$) were significantly higher with biofeedback however, posterior deltoid activity was significantly lower with biofeedback ($p = 0.01$). The infraspinatus muscle activity and muscle activity ratio were the highest in the isometric contraction type, and there were significant differences for all contraction types ($p < 0.05$). Whereas, the posterior deltoid activity was the lowest in the isometric contraction type, and showed a significant difference between isometric and other two contraction types ($p < 0.05$), but no significant different between concentric and eccentric contraction.

Conclusion: Our results indicate that the axial rotation biofeedback during sitting ER exercise might be effective method to activating selective infraspinatus muscle and recommended to enhance the dynamic stability of the shoulder joint.

INTRODUCTION

The stability of the shoulder joint is highly dependent on dynamic components, which is provided by the concavity compression mechanism through co-activation of the rotator cuff (RC) [1,2]. Among, the infraspinatus muscle is known to play a particularly important role in providing the primary external rotation (ER) torque and dynamic stability in the shoulder joint [3]. This muscle allows the inferior gliding of humeral head and provides the ability to control the anteroposterior translation of the humeral head and compressive forces through co-activation with the other RC [4,5].

Infraspinatus muscle weakness causes excessive posterior deltoid muscle activity relative to infraspinatus muscle activity [6-8], because of fiber orientation, the posterior deltoid might be activated during ER movement [9]. As a result, unwanted anterior translation of the humeral head during shoulder ER can result in internal or subacromial impingement [7,8]. In particular, repeated overhead throwing can increase the risk of shoulder injuries due to increasing contact pressure via distractive forces [10-12]. Therefore, selective activation of the infraspinatus muscle is important for rehabilitation [13,14].

Previous studies have suggested that efficient exercise methods for strengthening the infraspinatus muscle [13,15,16] among them the standing external rotation exercise is performed at 90° shoulder joint abduction and reported as effective exercise for strengthening the infraspinatus muscle [15,16]. Performing ER exercise at 90° shoulder joint abduction may provide a functional advantage because it replicates daily and sport-specific upper extremity function, by representing the influence of lever arm length on isometric tension generation [14,17-19]. This exercise can increase joint stability by producing a central compression force on humeral head [20] via the deltoid muscle and RC. However, despite these advantages, the failure of the humeral head to control axial rotation in the glenoid cavity can be increased the posterior deltoid activity [21]. Therefore, motor control training is required to selectively activate the infraspinatus while performing the ER exercises.

Biofeedback training is an effective method for promoting motor learning and control, which improves normal movement by controlling involuntary muscle contractions and selectively contracting the appropriate muscles [22-24]. In a study of biofeedback training for selective muscle activation of the infraspinatus, Lim et al. [25] reported increases in infraspinatus activity when performing the side-lying external rotation (SER) exercise using electromyography (EMG) biofeedback. Yu et al. [26] recently reported that increased the infraspinatus muscle activity and muscle thickness during the prone external rotation with pressure biofeedback. Therefore, biofeedback training can affect selectively activate muscles and performing ER exercises with biofeedback training can be expected to control axial rotation of the humeral head.

However, to our knowledge, no study has investigated the effectiveness of biofeedback training for axial rotation control of ER in the shoulder joints. Therefore, the purpose of this study was investigated that whether biofeedback for axial rotation was effective to activate selectively the infraspinatus through differences in muscle activity between the infraspinatus and posterior deltoid, and the activity ratio of the infraspinatus to posterior deltoid muscle during ER exercise in 90° abduction of shoulder joint.

MATERIALS AND METHODS

1. Participants

We used the G*power software (ver. 3.1.2; Franz Faul, Kiel University) to estimate the necessary sample size, in a pilot study of six participants comparing infraspinatus muscle activity during ER exercise with and without biofeedback. A power analysis determined that at least four subjects were required to achieve a power of 0.95 with an effect size of 1.79 at a significance level of 0.05. In total, 15 healthy males (age: 30.33 ± 2.58 years, height: 175.79 ± 3.82 cm, weight: 73.40 ± 3.46 kg) participated in this study. The inclusion criteria included absence of neck, shoulder, and upper extremity pain and ability to perform 90° shoulder abduction and 90° ER during exercise without pain. All participants provided informed consent, and the study was approved by the Inje University Ethics Committee for Human Investigation (IRB no. INJE-2018-09-010-001).

2. Surface Electromyography and Data Processing

A Trigno wireless system (Delsys, Inc.) was used to assess EMG signals. The system comprised a single EMG sensor (27 × 37 × 15 mm) containing two patent-pending stabilizing references, with a 4-bar formation electrode (5 × 10 mm) at an inter-electrode distance of 20 mm; the contact material was pure silver (99.9%). The EMG signal was filtered with 20–450 Hz band pass filter. The obtained surface EMG data were converted into the root mean square (RMS) with a 125-ms interval using the EMG Works 4.0 software (Delsys, Inc.) [27].

Two surface electrode pairs were placed on the infraspinatus and posterior deltoid and then maximal voluntary isometric contraction (MVIC) was measured to normalize the surface EMG data, following the methods of Magee [28] and Kendall et al. [29]. Each contraction was held for 5 seconds with maximal effort against manual resistance. The mean EMG data of middle 3-second of three trials was used [15]. Subjects took a 2-minute break between trials to minimize muscle fatigue.

3. External Rotation Exercise With and Without Axial Rotation Biofeedback

To avoid the compensatory movements that occur in the pelvis or lower limbs when ER exercise is performed in the sitting position, ER exercise was performed in an upright sitting position with the shoulder abducted 90°, elbow flexed to 90°, and forearm in a neutral position. In our study, a stick was placed in the center of the olecranon process of the elbow to provide biofeedback for axial rotation during ER exercise. The exercise was performed at an ER range of 90° divided into three phases: concentric, isometric, and eccentric. Subjects adjusted their position to prevent the stick from falling out of the olecranon process during exercise (Figure 1), and conducted the exercises

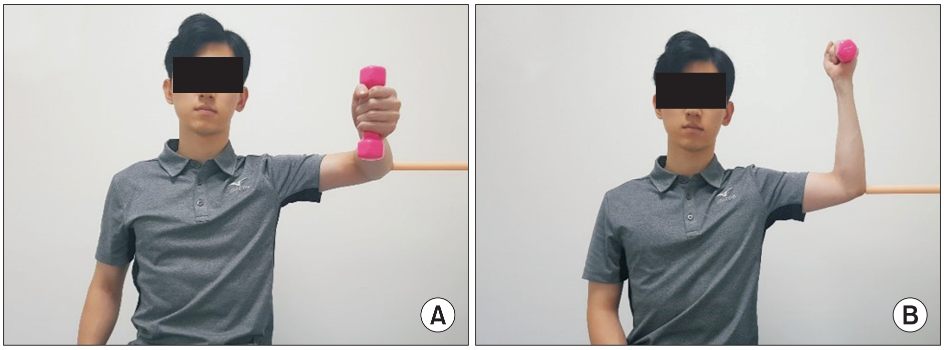

Figure 1. Sitting external rotation exercise with axial rotation biofeedback. (A) Starting position and (B) ending position.

under supervision to prevent compensation. Subjects externally rotated the dominant arm through a range of 90° for 5 seconds with concentric contraction, and then sustained an isometric contraction for 5 seconds at the end of the range, before finally returning to the start position at 0° ER for 5 seconds with eccentric contraction. The time for each type of contraction was controlled using a metronome. The subjects performed exercises using a 1–2 kg dumbbells, unwanted compensatory movements of the scapula during exercise may affect the results of muscle activity therefore, low intensity of resistance relative was provided using 1–2 kg dumbbells to control these bias in our study. In particular, in eccentric contraction subjects were asked not to apply downward force with the arms to prevent internal rotation by concentric contraction of the anterior deltoid and pectoralis major, which act as internal rotators as well as compensatory movements of the scapula. Subjects were asked to only slowly downward of the arms while bearing the weight of the dumbbells to internal rotation by eccentric contraction. The period of familiarization was provided sufficiently to accurately understand exercise methods for each muscle contraction type in advance prior to measurement. Subjects performed three trials in each contraction phase during ER exercise. EMG activity data were collected during the middle 3-second of the 5 seconds of measurement for each phase during exercise, with and without biofeedback. Mean values of EMG activity and the infraspinatus to posterior deltoid ratio were compared to identify differences between with and without biofeedback and among muscle contraction types.

4. Statistical Analyses

We used PASW ver. 18.0 for Windows (IBM Co.). A 2 (with and without biofeedback) × 3 (muscle contraction type) mixed-model repeated-measures analysis of variance (ANOVA) was used to determine: 1) the main effect of with and without biofeedback and muscle contraction type, and 2) the interaction effect between with and without biofeedback and muscle contraction type on the activity of the infraspinatus and posterior deltoid muscles, and muscle activity ratio. If significant differences were found, we used the Bonferroni correction for significant main effects and pair-wise comparison with Bonferroni correction for significant biofeedback × contraction type interactions. The significance level was set at $\alpha < 0.05$.

RESULTS

1. Infraspinatus Muscle Activity

There was a significant interaction effect between biofeedback and contraction type (F2,13 = 10.471, p = 0.002). Among all contraction types, muscle activity was higher in with than without biofeedback (Table 1). Muscle activity was highest during isometric contraction and significantly higher than in other contraction types with biofeedback (36.94 ± 11.86 %MVIC isometric vs. 28.86 ± 4.46 %MVIC concentric, p = 0.041; 36.94 ± 11.86 %MVIC isometric vs. 18.20 ± 4.89 %MVIC eccentric, p < 0.001). There was also a significant different between concentric and eccentric contraction (28.86 ± 4.46 %MVIC concentric vs. 18.20 ± 4.89 %MVIC eccentric, p < 0.001) (Figure 2). Without biofeedback, muscle activity was highest during isometric contraction, with a significant difference in muscle activity between all contraction types (28.15 ± 10.76 %MVIC isometric vs. 20.39 ± 5.65 %MVIC concentric, p = 0.033; 28.15 ± 10.76 %MVIC isometric vs. 15.87 ± 4.51 %MVIC eccentric, p < 0.001; 20.39 ± 5.65 %MVIC concentric vs. 15.87 ± 4.51 %MVIC eccentric, p = 0.034) (Figure 2).

2. Posterior Deltoid Muscle Activity

There were significant main effects of contraction type (F2,13 = 8.797, p = 0.004) and biofeedback (F1,14 = 18.456, p = 0.001).

Table 1. Mean ± standard deviation muscle activity and muscle activity ratio during concentric, isometric, and eccentric contraction, with and without biofeedback

Variable	Muscle contraction	Without biofeedback	With biofeedback	Mean difference (95% CI)	p-value
Infraspinatus (%MVIC)	Concentric	20.39 ± 5.65	28.86 ± 4.46	3.04 (0.45–5.63)	0.025
	Isometric	28.15 ± 10.76	36.94 ± 11.86	1.71 (0.44–3.86)	0.001
	Eccentric	15.87 ± 4.51	18.20 ± 4.89	3.13 (0.74–5.51)	0.014
Posterior deltoid (%MVIC)	Concentric	11.29 ± 6.60	7.97 ± 4.81	3.31 (1.41–5.21)	0.002
	Isometric	8.24 ± 3.42	6.01 ± 2.26	2.23 (0.93–3.53)	0.002
	Eccentric	10.19 ± 4.19	9.10 ± 3.57	1.08 (0.05–2.11)	0.040
Activity ratio	Concentric	2.38 ± 1.30	4.68 ± 2.47	−2.30 (−3.51 to −1.09)	0.002
	Isometric	3.81 ± 1.72	6.50 ± 2.02	−2.69 (−4.03 to −1.33)	0.002
	Eccentric	1.83 ± 1.11	2.23 ± 1.00	−0.39 (−0.85 to 0.06)	0.080

Values are presented as mean ± standard deviation. %MVIC, percentage of maximal voluntary isometric contraction; CI, confidence interval.

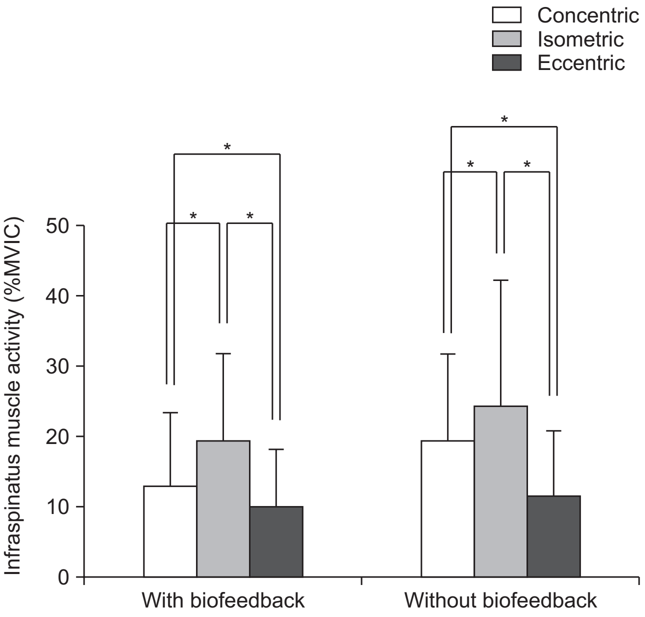

Figure 2. Comparison of infraspinatus muscle activity between muscle contraction types with and without biofeedback. %MVIC, percentage of maximal voluntary isometric contraction. *p < 0.05.

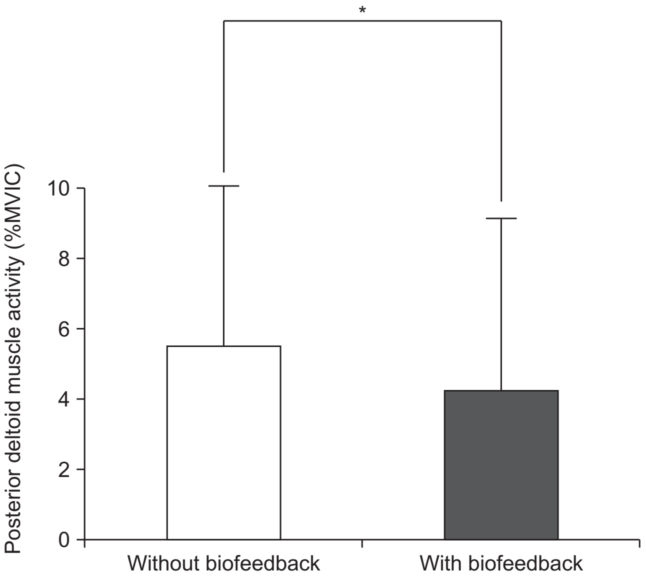

Figure 3. Comparison of posterior deltoid muscle activity with and without biofeedback. %MVIC, percentage of maximal voluntary isometric contraction. *p < 0.05.

However, there was no significant biofeedback × contraction type interaction effect (F2,13 = 2.231, p = 0.14). Muscle activity was significantly lower with than without biofeedback (7.70 ± 0.87 %MVIC with biofeedback vs. 9.91 ± 1.12 %MVIC without biofeedback, p = 0.001) (Figure 3), and muscle activity was lowest during isometric contraction, being significantly lower than during concentric (7.13 ± 0.68 %MVIC isometric vs. 9.63 ± 1.42 %MVIC concentric, p = 0.034) and eccentric contraction (7.13 ± 0.68 %MVIC isometric vs. 9.65 ± 0.97 %MVIC eccentric, p = 0.004). However, there was no significant difference between concentric and eccentric contraction (9.63 ± 1.42 %MVIC concentric vs. 9.65 ± 0.97 %MVIC eccentric, p = 1.00) (Figure 4).

3. Infraspinatus to Posterior Deltoid Muscle Activity Ratio

There was a significant biofeedback × contraction type interaction effect (F2,13 = 8.038, p = 0.005). The muscle activity ratio was higher with than without biofeedback during concentric and isometric contraction however, there was no significant difference in the muscle activity ratio during eccentric (Table 1). The muscle activity ratio was highest during isometric contraction with biofeedback and significantly higher than among the other contraction types (6.50 ± 2.02 %MVIC isometric vs. 4.68 ± 2.47 %MVIC concentric, p < 0.001; 6.50 ± 2.02 %MVIC isometric vs. 2.23 ± 1.00 %MVIC eccentric, p < 0.001). There was also a significant different between concentric and eccentric contraction (4.68 ± 2.47 %MVIC concentric vs. 2.23 ± 1.00 %MVIC eccentric, p = 0.004) (Figure 5). The

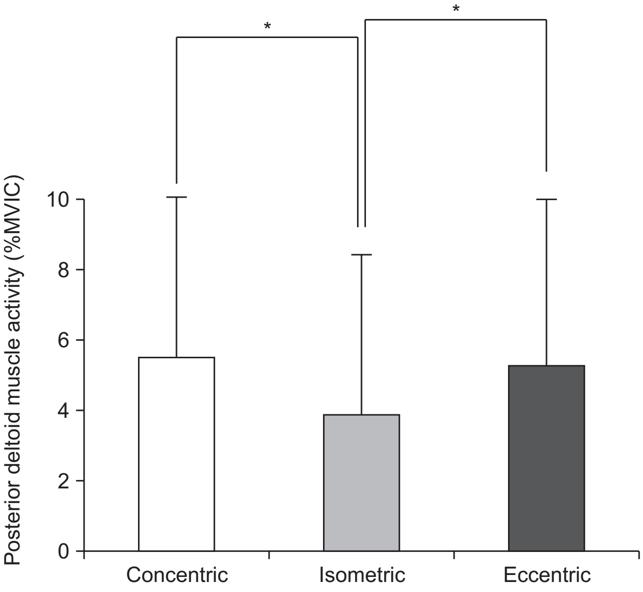

Figure 4. Comparison of posterior deltoid muscle activity between muscle contraction types. %MVIC, percentage of maximal voluntary isometric contraction. *p < 0.05.

muscle activity ratio for trials without biofeedback was highest during isometric contraction and significantly higher than other contraction types (3.81 ± 1.72 %MVIC isometric vs. 2.38 ± 1.30 %MVIC concentric, p = 0.001; 3.81 ± 1.72 %MVIC isometric vs. 1.83 ± 1.11 %MVIC eccentric, p = 0.002). However, there was no significant difference between concentric and eccentric contraction (2.38 ± 1.30 %MVIC concentric vs. 1.83 ± 1.11 %MVIC eccentric, p = 0.45) (Figure 5).

DISCUSSION

The aim of the current study was to investigate whether biofeedback for axial rotation was effective to activate selectively the infraspinatus through differences in muscle activity of the infraspinatus and posterior deltoid, and the activity ratio of the infraspinatus to posterior deltoid. Infraspinatus muscle activity was higher with axial rotation biofeedback than without biofeedback. These results suggest that axial rotation biofeedback training might be recommended for selective muscle activation of the infraspinatus.

The compressive force of the RC muscles not only maintains the humeral head centrally within the glenoid, but also reduces the shear forces. However, failure of the RC muscles to control the humeral head can alter the rotational axis and change normal kinematics [30]. When performing arm elevation, translation of the humeral head by about 1–1.5 mm based on the center of the glenoid cavity, was observed in subjects with impingement, an RC tear, or shoulder muscle fatigue [20,31,32]. This increased translation of the humeral head may contribute to shoulder pathologies such as impingement.

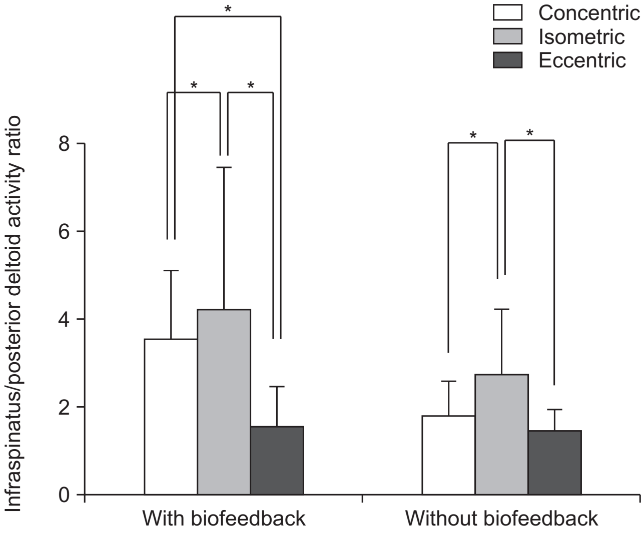

Figure 5. Comparison of infraspinatus to posterior deltoid muscle activity ratios between muscle contraction types with and without biofeedback. *p < 0.05.

This study confirmed that muscle activity of the infraspinatus was higher in axial rotation biofeedback than without biofeedback among all muscle contraction types. These results can be explained by increased concavity compression due to control of humeral head translation during biofeedback training. Concavity compression refers to the compression of the humeral head into the concave glenoid fossa, which contributes to stabilizing the shoulder joint [20,33]. Subjects were provided biofeedback during the exercise, allowing them to adjust such that the axis of rotation could be kept constant. This improved motor control; better positioning of the humeral head within the concave glenoid fossa resulted in increased concavity compression forces and increased muscle activity of the infraspinatus under the biofeedback condition in our study. Among contraction types, infraspinatus muscle activity was higher in the order isometric > concentric > eccentric. Isometric contraction is useful to improve joint stability and has been reported to improve muscle strength by 60%–80% [34,35]. Torque values for the three contraction types could not be compared in the current study; however, unlike concentric and eccentric contraction, in which muscle length is continuously altered, muscle activity was likely higher during isometric contraction due to the constant production of internal torque, as the length of the muscle was not altered during exercise. Therefore, the results of our study theoretically support use of isometric exercise effect for stability improvement, and suggest that isometric exercise is more effective than concentric or eccentric exercise. In our study, concentric contraction produced higher muscle activity than eccentric contraction. These results are explained by force-velocity relationship in which concentric torque increases along with a decreasing velocity, and eccentric torque increases as the velocity increases [36,37]. In our study, subjects performed exercises for 5 seconds per contraction type; because of their relatively slow speed, muscle activity was significantly higher during concentric contraction than during eccentric contraction. Given the findings of our study, we expect that concentric contraction at low velocity will prove more effective for selectively activating the infraspinatus muscle.

Posterior deltoid activity was lower with axial rotation biofeedback than without biofeedback. In our study, we observed posterior deltoid activity of 8.24 and 6.01 %MVIC with and without biofeedback, respectively, during isometric contraction. These results suggest that the muscle activity required for the infraspinatus to produce ER torque was higher than for the posterior deltoid during biofeedback training, leading to decrease in posterior deltoid muscle activity. Indeed, the results of infraspinatus to posterior deltoid activity ratios observed in the current study were approximately 2–6 for all contraction types with biofeedback training; these values were significantly higher than those without biofeedback training during concentric and isometric contraction. These findings similar from those of Lim et al. [25] who reported infraspinatus to posterior deltoid ratios for SER exercise with and without EMG biofeedback of 10.23 and 6.31, respectively. Recently Yu et al. [26] reported muscle activity ratios of approximately 3–5 with pressure biofeedback training, which were significantly higher than those without biofeedback. These results indicate greater activation of the infraspinatus is than the posterior deltoid during axial rotation biofeedback, particularly in isometric contraction. Based on these findings, we recommend axial rotation biofeedback strategy when performing the ER exercise in 90° abduction position for selective activation of the infraspinatus and simultaneous reduction of posterior deltoid activity, and a strategy like this is expected to prevent the shoulder injuries.

This study has several limitations. We investigated only healthy males in their 20s with similar physical characteristics. Future research should investigate the effects of axial rotation biofeedback exercise in patients with shoulder pathologies such as shoulder impingement and should include females and subjects of various ages. We did not confirm the kinematics of humeral head translation or muscle activities surrounding the scapula during exercise; these variables should be examined in future studies of axial rotation biofeedback training. Finally, by the length-tension relationship of muscle, active tension of muscle is the most increased in the mid-range of joint but the muscle activities of isometric contraction were measured at the end-range of joint in the current study. Therefore, future studies are needed to consider that reflects the characteristics of the muscle-length tension relationship.

CONCLUSIONS

We confirmed muscle activity in the infraspinatus and posterior deltoid muscles during axial rotation biofeedback training. Our study demonstrated that axial rotation biofeedback training significantly increased infraspinatus muscle activity and the infraspinatus to posterior deltoid muscle activity ratio, while decreasing posterior deltoid muscle activity during axial rotation biofeedback training. In particular, the muscle activity of the infraspinatus was highest during isometric contraction. Our findings show that axial rotation biofeedback is a novel and effective method for selectively activating the infraspinatus muscle while minimizing activation of the posterior deltoid muscle when performing the ER exercise in a 90° abducted shoulder position. These findings might be able to help clinicians design effective exercise program to enhance shoulder joint stability.

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CONFLICTS OF INTEREST

No potential conflicts of interest relevant to this article are reported.

AUTHOR CONTRIBUTION

Conceptualization: IY, JO. Data curation: IY. Formal analysis: IY. Investigation: IY. Methodology: IY, MK. Project administration: IY, JO. Resources: IY. Software: IY. Supervision: IY, JO. Validation: IY. Visualization: IY, MK. Writing - original draft: IY. Writing - review & editing: IY, MK, JO.

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