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# Infraspinatus fatigue during resisted arm elevation with isometric contraction: an electromyographic study

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**Background:** Various forms of resistance are used in rotator cuff training programs. However, the muscular activity of the infraspinatus during arm elevation has not been clarified in detail. We aimed to evaluate infraspinatus fatigue during resisted arm elevation in various positions.
**Methods:** The dominant (right) shoulders of 39 healthy subjects were examined. Average mean power frequency shifts of the infraspinatus and deltoid were evaluated electromyographically when the subjects performed isometric contractions equivalent to 30% of the maximal voluntary isometric contraction force for 60 s during 90° arm elevation in the sagittal and scapular planes, prone and side-lying external rotations, and repeated side-lying external rotation exercise. Further, the arm-elevation force was measured before and after the repeated external rotation exercise. Analysis of variance and paired *t* tests were used for statistical analyses; differences at $P < .05$ were considered significant.
**Results:** The infraspinatus was fatigued easily during resisted arm elevation in the sagittal plane compared with the scapular plane ($P < .01$). Comparisons of sagittal-plane elevation with side-lying and prone external rotations revealed no significant differences in the fatigue levels. The arm-elevation force after the repeated external rotations was significantly decreased in the sagittal plane compared with the scapular plane ($P < .01$).
**Conclusion:** In clinical settings, this data may be helpful in knowing how to helpful to protect the infraspinatus after surgical repair. Therefore, therapeutic exercise regimes with resisted arm elevation should avoid infraspinatus overfatigue in the sagittal plane in the early postoperative period.
**Level of evidence:** Basic Science Study, Kinesiology Study.


**Keywords:** Infraspinatus; muscular fatigue; arm elevation; electromyography; mean power frequency; repetitive external rotation; therapeutic exercise; biomechanics

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The infraspinatus acts as an external rotator to stabilize the glenohumeral joint.[7,8,18,35] Several researchers have indicated that this muscle also contributes to arm elevation.[19,26,30] A recent anatomical study has demonstrated that the infraspinatus occupies about half of the highest impression on the greater tuberosity, which was believed to be the footprint of the

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supraspinatus, thus supporting the concept that the infraspinatus contributes more to arm elevation than previously believed.[24]

The scapular plane has been identified as the most efficient plane for the arm-elevation maneuver.[15] According to Johnston,[15] scapular-plane elevation allows the arm to achieve the full benefit of scapular rotation. He also believed that the arm experiences the least fatigue in this position, because of the relaxed orientation of the deltoid and rotator cuff muscles and the untwisted configuration of the inferior joint capsule.[15,28] It is also the ideal position to obtain full postoperative passive range of motion without stressing the capsular or musculotendinous repair.[1] Consequently, isotonic rehabilitation exercise for the rotator cuff and deltoid muscles is commonly performed in the scapular plane.[31]

Surface electromyography (EMG) is a valid and reliable tool to measure muscle fatigue.[9,16,20,22,25] Although surface EMG has limitations related to electrode placement, skin impedance, and cross-talk, it has been used to evaluate the degree of fatigue of different muscles.[21,25] Hagberg[13] found a mean power frequency (MPF) decrease in a fatiguing contraction due to alterations in the muscle energy metabolism; this decrease in the conduction velocity of the muscle fibers causes a shift in the power spectra toward lower frequencies. Similarly, Gerdle et al[12] demonstrated that MPF shifts are consistent with mechanical muscular fatigue and associated with a considerable degree of local muscular fatigue; they also showed that the fatiguing phase correlates with an increasing degree of fatigue of type-II motor units.

Biomechanical/EMG studies have focused on the infraspinatus activity during arm elevation in the scapular or coronal plane,[1,17,23,26,30,31,34] but not on its activity during arm elevation in the sagittal plane. Considering that assessment of infraspinatus activity will enhance our understanding of the muscle function during arm movements, we aimed to evaluate infraspinatus fatigue during resisted isometric arm elevation in various positions by EMG. Our hypothesis was that during resisted arm elevation, the infraspinatus is fatigued easier in the sagittal plane than in the scapular plane.

## Materials and methods

### Subjects

We examined the dominant shoulders of 39 right-handed subjects. No subject had any history of shoulder pain or injuries before participating in this study. Their mean age was 21.2 years (range, 20−26), mean height was 170.7 cm (range, 159−178), and mean weight was 62.8 kg (range, 55−68).

### Experimental procedures

Infraspinatus and deltoid activities were recorded by EMG. The electrode placement locations were selected according to published studies involving EMG data collection from the muscles of interest.[27] For the infraspinatus, electrodes were placed 2 fingerbreadths inferior to the center of the spina scapulae. For the anterior deltoid, electrodes were placed three fingerbreadths inferior to the anterior border of the acromion process. For the middle deltoid, electrodes were placed midway between the deltoid tuberosity and the acromion process. For the posterior deltoid, electrodes were placed 2 fingerbreadths inferior to the posterior margin of the acromion process. A ground electrode was placed on the acromion process.

MyoSystem 1200 (Noraxon U.S.A., Inc, Scottsdale, AZ, USA) was used to collect raw surface EMG data. This unit provides signal amplification of 1000×, 20−500 Hz band-pass filtering, a common-mode rejection ratio greater than 100 dB, and input impedance greater than 10 MΩ. Output from the unit was linked to a 16-bit analog-to-digital converter in a personal computer, and the raw data were monitored and collected in MyoResearch 2.11 (Noraxon U.S.A., Inc) at 1024 Hz. The skin was prepared by scrubbing the area with alcohol pads, and the electrodes were applied parallel to the muscle fibers. Self-adhesive bipolar surface electrodes (Medicotest Blue Sensor, Chicago, IL, USA) were then attached. Correct electrode placement was confirmed by observing all EMG signals on an oscilloscope during resisted contractions of each muscle.

### Force loading

Each subject was seated upright on a chair. Then, force loading was applied with the shoulder at 90° elevation in the sagittal or scapular plane and the elbow extended 0° with the forearm midway between the thumb-up and thumb-down positions (Fig. 1, *A-D*). Force loading was also applied during side-lying external rotation (ER) supported by a towel roll with the arm abducted at 10−20° and the elbow flexed at 90°,[6] and during prone ER with the arm abducted at 90° and externally rotated at 90°.[6] Shoulder muscular fatigue was measured when the subjects performed isometric contractions equivalent to 30% of the maximal voluntary isometric contraction (MVIC) force for 60 sec in the described positions.

The MVIC force was measured twice by a PowerTrack II Commander handheld dynamometer (JTech Medical Industries, Salt Lake City, UT, USA) before this experiment. The sensor pad of the handheld dynamometer was placed on the distal forearm and fixed with a strap. A posture hold bar and cephalic strap were used to minimize motion during the experiment. The mean value of the two trials at 100% MVIC force was obtained and the 30% MVIC force was then calculated.

### Repeated ER exercise

Repeated ER exercise was performed according to the method of Wakabayashi et al.[33] In brief, side-lying ERs were performed repeatedly with a dumbbell of 3 kg, until at least 30% reduction in the maximum ER force was achieved. Before and after this exercise, the arm-elevation force in the sagittal and scapular planes was measured by the dynamometer in the same position as already described. Then, changes in the arm-elevation force before and after the exercise were calculated.

### Data reduction

Muscular fatigue was defined as a decrease in MPF output over time. The MPF was derived from the raw EMG data by using