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The Effects of Muscle Fatigue on Shoulder Joint Position Sense*

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ABSTRACT

Proprioception, or joint position sense, probably plays an important role in shoulder joint function. In this study, we assessed the effect of muscle fatigue on shoulder proprioception in 20 volunteers with no shoulder abnormalities. Shoulder proprioception was measured as the threshold to first detection of humeral rotation with the joint at 90° of abduction and 90° of external rotation. Subjects were tested while rested, exercised on a isokinetic testing machine until fatigued, and then retested in an identical fashion. Both shoulders were tested, and the order of dominant and nondominant shoulder was randomized. Shoulder proprioception was analyzed for its dependence on arm dominance, direction of rotation, and muscle fatigue. Subjects detected external rotation after significantly less movement than they did internal rotation. Overall, before exercise, motion was detected after a mean of 0.92° of rotation. After exercise, this threshold to detection of movement increased to 1.59°, an increase of 73%. This significant increase occurred with both internal and external rotation. The decrease in proprioceptive sense with muscle fatigue may play a role in decreasing athletic performance and in fatigue-related shoulder dysfunction. It remains to be determined if training can lessen this loss in position sense.

Although joint proprioception, with the exception of the knee joint, has not been widely studied, it likely plays an important role in joint function and performance. Fine motor coordination requires accurate afferent input from the joints and muscles involved. These signals probably come from mechanical receptors in the periarticular soft tissues. In the shoulder, the rotator cuff muscles, tendons, and joint capsule are likely sources of such signals. Jerosch et al.,[6] in studying human cadaveric shoulder capsules, found neural axons of various diameters in the capsular ligaments that had no relation to blood vessels or vessel walls directly. They concluded that these axons were involved in shoulder joint proprioception. Similarly, Vangsness and coworkers[11] found proprioceptive nerve endings in the glenohumeral joint capsular ligaments and free nerve endings in the glenoid labrum. These structures likely provide important neural input on joint position and strains. Because articular cartilage contains no neural elements, it is less likely that the actual joint surfaces play a major role in proprioceptive sense.

Intact joint position sense is necessary for normal muscle coordination and timing. It has become evident that active muscle forces play a significant role in shoulder joint stability.[2,4,5,7] This can occur through compression of the humeral head into the glenoid cavity or by the tendons of the muscles, which can provide a mechanical block to excessive translation. It has also been shown that shoulder joint dysfunction may be associated with deficiencies in joint proprioception. If muscle coordination is impaired as a result of deficient proprioception, symptomatic shoulder instability can occur. In a study of patients with symptomatic shoulder instability, Smith and Brunolli[10] found significantly worse proprioception in the injured shoulders of patients with unilateral recurrent anterior dislocations compared with their uninjured shoulders. Even more convincing are the findings of two independent investigations demonstrating proprioceptive defects in unstable shoulders that then returned to normal after successful surgical reconstructions.[8,12]

It is not known whether shoulder joint proprioception is affected by muscle fatigue and what effect this might have on upper extremity performance. Previous studies have evaluated proprioception thresholds in rested normal shoulders, but no studies have evaluated the effect of exercise on shoulder proprioception. Frequently, upper extremity motor performance is seen to deteriorate with

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muscle fatigue, but this may occur simply because of decreased muscle contraction force or reaction time. We hypothesized that shoulder joint proprioception is significantly worse when the shoulder muscles are fatigued and that this plays a role in exercise-related shoulder dysfunction. A better understanding of shoulder proprioception and its role in the athlete may help in the design of rehabilitation and conditioning programs for athletes with shoulder dysfunction, especially instability.

MATERIALS AND METHODS

Joint proprioception is commonly measured by one of two techniques. It can be measured as the threshold to detection of the initiation of movement of a joint at rest, or by the ability to return to a specific known position of a joint. In a previous study of shoulder proprioception in subjects with no shoulder abnormalities, we found the threshold to motion detection to be a more reliable and reproducible technique[3]; thus, this is the technique used in this current study. Twenty healthy volunteers (11 male and 9 female) with an age range from 19 to 30 years (mean, 23.7) participated in this study. There was no history of shoulder injury, surgery, or medical problems in any of the volunteers. All subjects had range of motion within normal limits and, specifically, no patients had difficulty or discomfort with the shoulder in the testing position. No attempt was made to include or exclude volunteers on the basis of shoulder or generalized joint laxity found by examination.

The proprioception measurement protocol was reviewed and approved by the University of Michigan Institutional Review Board and informed consent was obtained from all patients. Proprioception was measured with the subjects in the seated position, backs vertical, with the shoulder positioned at 90° of abduction, 90° of external rotation, and in the plane of the scapula (30° in front of the frontal plane) (Fig. 1). The forearm was perpendicular to the floor. This position was selected to simulate the abducted, externally rotated position of the shoulder required in many sporting activities. The elbow was immobilized at 90° of flexion, and the forearm was secured to a padded rotating arm with its axis along the humeral shaft. This rotating arm was driven by a hand crank through a step-down gear with a ratio of 60:1. This setup allowed movement at the shoulder to be isolated to internal and external rotation along the shaft of the humerus. To measure the shoulder position, a rotational variable differential transducer was fixed to the axis of the rotating arm.

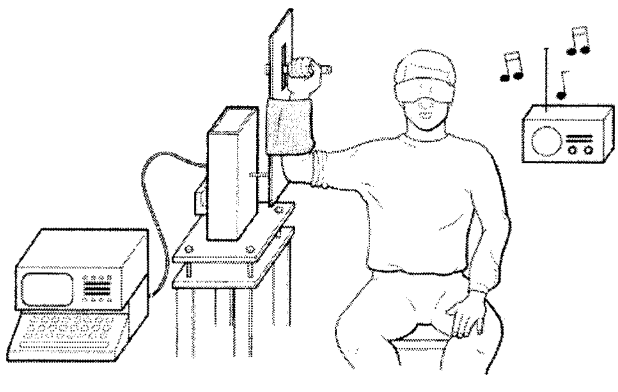

Figure 1. Apparatus and position for testing of shoulder proprioception. The shoulder is positioned at 90° of abduction, 90° of external rotation, in the plane of the scapula. Motion is restricted to internal and external rotation.

The subjects were familiarized with the testing device and the protocol. To do this, each subject sat in the testing chair, placed his or her arm in the testing apparatus, and went through a short mock test to ensure comfort and understanding of the test protocol. The subjects were then blindfolded, and one shoulder was placed in the testing device. Without warning of initiation, the shoulder was internally or externally rotated in a randomized sequence at 1 deg/sec. Subjects indicated when they first detected motion of the shoulder and at that point the motion was stopped. The difference between the starting position and the position when the motion was first detected was recorded as the threshold to detection of movement. This procedure was repeated until 10 cycles in each direction of rotation (internal or external) were correctly identified. The mean rotational displacement from these 10 cycles was used as the measure of proprioception.

The same arm was then exercised in internal and external rotation using an isokinetic testing machine (Biodex Medical Systems, Shirley, New York) at 180 deg/sec. The subjects were instructed to perform at maximal effort. Internal rotation peak torque at the beginning of the exercise session was determined, and the subject was exercised until this peak torque decreased by 50% consistently. Exercise was then discontinued. All subjects reported a sensation of tiredness or fatigue, yet none had symptoms of pain or instability. Internal and external rotation torque, number of repetitions, and work energy were measured and recorded by the testing machine. The subject then stopped the exercise session and his or her shoulder was immediately retested for proprioception as previously described. All testing was completed within 5 minutes of the end of the exercise session. The contralateral shoulder was then tested in an identical manner. The order of testing (dominant or nondominant first) was randomized.

Shoulder proprioception in this study is defined as the threshold to detection of rotation and was analyzed for its dependence on arm dominance, direction of rotation (internal or external), and muscle fatigue using an analysis of variance (ANOVA).

RESULTS

In these healthy subjects, motion was initially detected after a mean rotation of 0.92° (SD, 0.20°; range, 0.52° to 1.80°). We found no difference in proprioceptive sense between the dominant and nondominant sides ($P = 0.86$). However, we did find a difference in initial detection of movement between internal rotation and external rotation movement. On average, in rested shoulders, internal

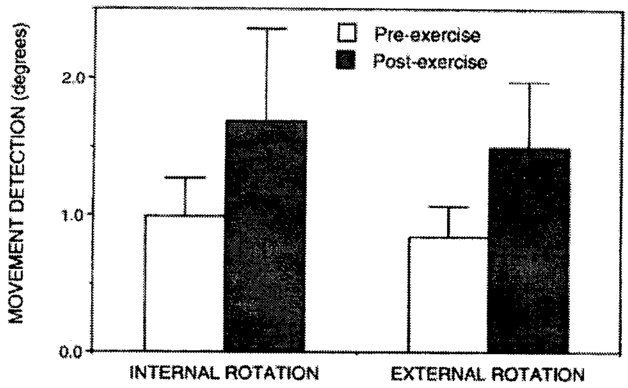

Figure 2. The mean threshold to detection of movement (±SD) before and after fatiguing exercise for internal and external rotation. Joint position sense worsened significantly ($P < 0.001$) with muscle fatigue.

rotation was detected after 0.99° (SD, 0.24) and external rotation after 0.84° (SD, 0.23). This difference was statistically significant ($P < 0.05$).

For analysis, muscle fatigue was defined as the quotient of work energy of the initial 30 repetitions minus work energy of the final 30 repetitions divided by work energy of the initial 30 repetitions (Percentage fatigue = [Work of initial 30 reps − Work of final 30 reps]/Work of initial 30 reps). Fatigue averaged 46% over the course of the exercise period. There was no difference between the dominant and nondominant sides.

After exercise, the mean threshold to detection of movement (both internal and external rotation combined) increased to 1.59° (SD, 0.59°), an increase of 73%. When viewed separately, internal rotation proprioception worsened by an average of 0.70°, to 171% of initial baseline levels (Fig. 2). Similarly, external rotation threshold increased by 0.66°, to 179% of preexercise levels. This effect of exercise was found to be statistically significant at $P < 0.001$. The degree of muscle fatigue was not found to correlate significantly with the relative decrease in position sense for each individual subject ($P = 0.92$).

DISCUSSION

The results of proprioceptive testing in these healthy volunteers before exercise agree closely those we found in a previous study of volunteers.[3] Using the same technique for measurement in both groups, we found that shoulder rotation was detected after approximately 1° of rotation. In each study, the shoulders were more sensitive to external rotation than to internal rotation. We hypothesized that this difference occurs because of a relative tightening of the capsular ligaments and rotator cuff tendons as the shoulder externally rotates from the abducted externally rotated position. On the other hand, internal rotation from the externally rotated position toward the neutral position relaxes the capsule and rotator cuff. This same finding was reported previously in a group of healthy, rested volunteers.[3]

Although our apparatus differs from what other investigators have used, our values for the initial detection of humeral rotation are comparable. The values we report in this study are quite similar to those reported by Smith and Brunolli[10] for their patients tested in a different apparatus. In their patients with no shoulder abnormalities they reported thresholds to detection of movement of 1.18° with the dominant shoulder and 1.04° for the nondominant shoulder. They found this increased to 2.58° in shoulders with recurrent anterior dislocations. Similarly, Lephart et al.,[8] using a device similar to that used by Smith and Brunolli, studied 40 volunteers with no shoulder problems and found mean threshold to detection of movement values of 1.4° to 2.2°. Both studies, as well as that by Zuckerman et al.,[12] documented increases in these thresholds (indicating worsening of position sense) in shoulders with symptomatic anterior instability. In these studies, surgical repair in the form of open anterior capsular repair restored proprioception to the level of the contralateral, uninjured side. This fact suggests that a retensioning of the anterior capsule, as is commonly performed to prevent recurrent dislocation, can restore joint position sense.

The current study addresses the effect of exercise and muscle fatigue on shoulder proprioception. We have demonstrated that fatiguing exercise can significantly reduce joint position sense. In our volunteers the threshold to detection of movement after exercise increased to 173% of what it was when the subject was rested. It can be hypothesized that if fatigue interferes with position sense, shoulder function might be impaired by loss of the normal muscle coordination, which helps to provide joint stability.

Although no other studies have addressed the effect of muscle fatigue in proprioception of the shoulder, Skinner et al.[9] have evaluated its effects on position sense at the knee joint. They found that after exercise there was a significant worsening in the ability to reproduce knee joint angle compared with the preexercise condition. They concluded that joint position sense was significantly affected by fatigue, that muscle receptors are a prominent if not primary determinant of joint position sense at the knee, and that capsular receptors may have a secondary role.

Although we did not measure the reproduction of joint position in our study, our finding that the threshold to detection of movement worsened with muscle fatigue is in agreement with the findings of Skinner et al. and support the contention that proprioception may come in part from afferent signals from receptors in muscle. Another explanation may be that muscle fatigue somehow decreases the sensitivity of capsular receptors and thus decreased proprioceptive sense indirectly.

The fact that shoulder joint proprioception does worsen with muscle fatigue raises the question as to whether muscle training can somehow decrease this loss of position sense. This was not addressed in our study. However, in another of their series of studies on proprioception of the knee joint, Barrack et al.[1] studied highly conditioned professional ballet dancers to determine the effect of training on their proprioception. Paradoxically, they found that these dancers performed significantly better in their threshold to their detection of movement and significantly worse in their ability to reproduce a joint position than an age-matched control group. The authors believed that athletic training can effect joint proprioception and that possibly these two tests for proprioception depend on different neural mechanisms.

It is entirely unknown whether training can actually change a person's proprioception sensitivity or change the way position sense is affected by muscle fatigue effects. If the decrease in proprioceptive sense that occurs with muscle fatigue plays a significant role in the deterioration of performance with fatigue, it is possible that endurance training might improve performance by reducing this loss in joint position sense. Thus, our findings have significance for athletic training as well as rehabilitation.

In conclusion, in a group of volunteers with no shoulder problems, the shoulder joint is quite sensitive to humeral rotation, with movement generally detected after only 1° of rotation. There was no difference between dominant and nondominant shoulders, but sensitivity to external rotation was greater than that to internal rotation by a significant degree at the 90° of abduction and 90° of external rotation position. In addition, shoulder joint proprioception is significantly worsened by fatiguing exercise. These findings suggest the existence of both capsular and muscular components of shoulder position sense. It is possible that this decrease in shoulder proprioception that accompanies muscle fatigue may be lessened with proper training, providing for a higher level of sustained upper extremity performance. The effects of training need to be further studied in controlled trials.

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