Physical Therapy
Journal of the American Physical Therapy Association and de Fysiotherapeut
Royal Dutch Society for Physical Therapy

PTJ

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PHYS THER. 2012; 92:563-573.
Originally published online January 6, 2012
doi: 10.2522/ptj.20110236

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Background. Altered neuromuscular control due to compromised joint position sense may contribute to recurrent shoulder instability.

Objective. The purpose of the present study was to examine whether individuals with anterior shoulder instability exhibit larger shoulder position sense errors than those with healthy shoulders in both passive matching and active positioning.

Design. This was a between-groups study with repeated measures.

Methods. Ten people with anterior shoulder instability and 15 people with healthy shoulders participated in the study. Shoulder position sense was examined with 3 different protocols (passive motion to remembered shoulder rotation angles and active shoulder abduction and rotation to verbally specified positions) in positions of both mid-range and end-range of motion.

Results. Participants with unstable shoulders exhibited significantly larger errors (by 1.8° on average) in perception of shoulder position compared with those with healthy shoulders during passive matching. During active positioning, participants with unstable shoulders were able to voluntarily move the shoulder to verbally specified angles as accurately as those with healthy shoulders in both abduction (0.85° difference) and rotation (0.99° difference) tasks.

Conclusions. Results of this study indicate that people with unstable shoulders can perceive shoulder angles as accurately as people with healthy shoulders in activities with voluntary arm movements. Compared with passive matching, better information from muscle spindles and other sources during voluntary arm movements may compensate for the potential joint position sense deficits after the injury. Therefore, individuals with an unstable shoulder may have adequate neuromuscular control to engage proper protective mechanisms to stabilize the shoulder joint during functional activities.

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[Hung Y, Darling WG. Shoulder position sense during passive matching and active positioning tasks in individuals with anterior shoulder instability. *Phys Ther.* 2012;92:563–573.]

Published Ahead of Print: January 6, 2012
Accepted: December 19, 2011
Submitted: July 28, 2011

A decrease in shoulder stability due to compromised soft tissues is commonly seen in athletes whose sport, such as baseball, demands strong repetitive overhead movements, as well as in individuals who have experienced glenohumeral joint (GHJ) dislocation as a result of acute trauma such as a fall.[1–3] After the first episode of anterior shoulder dislocation, injured passive shoulder stabilizers may not be able to provide sufficient mechanical stabilization to maintain the humeral head within the glenoid cavity, especially in shoulder positions involving abduction with external rotation (ER).[4–7] Altered neuromuscular control over shoulder muscles due to compromised proprioceptive sensation also may contribute to recurrent shoulder instability.[8–13] Without proper neuromuscular coordination, the individual may not have proper dynamic stability by engaging appropriate muscle activation at positions in which voluntary contraction of active joint stabilizers is crucial for shoulder stability.[9,12]

Significant joint position sense differences have been reported between individuals with healthy shoulders and those with unstable shoulders.[9,12–14] However, shoulder position sense was commonly analyzed using the "passive matching of passive positioning" protocols, in which the person's arm was moved passively with an apparatus in both the initial and the matching trials without visual guidance.[9,12–14] Hence, it is not clear whether people with unstable shoulders also exhibit joint position sense deficits during voluntary movements used in most daily activities. When an individual actively moves the unsupported arm to various shoulder locations, muscle spindles and Golgi tendon organs (GTOs) of shoulder muscles may become more sensitive to joint angle changes.[15–18] Evidence suggests that information from muscle spindles may be the primary input for perception of joint angles, as previous work has shown that joint receptor inputs are not necessary for accurate perception of joint angles at digit joints.[19,20] During voluntary movement, additional information of central origin (eg, effort) will be available.[17,21,22] Activating shoulder muscles for abduction and rotation may minimize anterior translation of the humeral head and enhance GHJ stability.[7,23–27] Therefore, people with unstable shoulders may have better shoulder position sense during voluntary movements than during passive movements.

There are only a few studies that involved active movement of unstable shoulders during shoulder position sense testing.[28–31] However, some procedures did not examine the end-range of motion where vulnerable shoulder structures are stressed and shoulder dislocations are most likely to recur.[28,29,31] In addition, reproducing a remembered target[28–31] can be affected by the person's cognitive status, environmental settings, and procedural factors. Moreover, being able to reproduce a remembered location does not indicate whether people can accurately move their shoulders to "intended positions" without copying a prior movement, as in most of the daily activities. Thus, results of earlier studies may not accurately reflect shoulder position sense at a functional level, and the current shoulder position sense testing techniques may not provide clinicians with the most accurate and consistent evaluation of a shoulder injury.

The purpose of the present study was to examine whether individuals with anterior shoulder instability exhibit larger shoulder position sense errors than those with healthy shoulders in both passive matching and active positioning. Our first hypothesis was that individuals with unstable shoulders would exhibit larger position errors than those with healthy shoulders in reproduction of remembered shoulder rotation angles during passive matching, and the difference between the 2 groups would be greater near the end-range of motion where the GHJ is most unstable. Our second hypothesis was that individuals with unstable shoulders and those with healthy shoulders would exhibit similar joint position sense errors during active positioning, and the difference between the 2 groups would remain the same at mid-range or end-range shoulder positions. The goal of the study was to assist clinicians and researchers in developing appropriate shoulder position sense diagnostic and testing techniques and in implementing proper rehabilitation programs for individuals with anterior shoulder instability.

Method

Participants

Ten individuals with a history of anterior shoulder dislocation (3 female and 7 male, aged 19–37 years) and 15 individuals with healthy shoulders (4 female and 11 male, aged 20–39 years) volunteered for this study (Table). All participants signed informed consent documents approved by the Institutional Review Board of the University of Iowa. Inclusion criteria for the participants with unstable shoulders included having a minimum of one episode of anterior shoulder dislocation documented in their medical record, a positive apprehension test administered by the primary investigator, and no surgical repair prior to the testing. People with multidirectional instability, degenerative arthritis, muscle weakness (weaker than "normal" with manual muscle testing [MMT]), and the inability to achieve the designated shoulder positions without pain or apprehension were excluded from the study. People

Table.
Physical and Injury Characteristics of Participants With Unstable Shoulders (U1–U10) and With Healthy Shoulders (S1–S15)[a]

Participant	Sex	Age (y)	No. of Dislocations	Time Since Last Injury (mo)	Frequent Activities	First Dislocation Activity	Recurrent Dislocation Activity
U1	M	19	2	16	Recreational skateboarding, weight training	Skateboarding	Skateboarding
U2	F	21	3	19	Competitive gymnastics	Gymnastics	Gymnastics
U3	M	27	2	12	Weight training	Fall	Fall
U4	F	37	1	7	None	Fall	NA
U5	M	19	5	6	Recreational basketball	Skiing	Skiing, soccer, water tubing
U6	M	23	1	18	Recreational basketball	Basketball	NA
U7	M	28	2	12	Recreational basketball, weight training	Basketball	Basketball
U8	M	22	1	2	Recreational football, basketball	Football	NA
U9	F	20	2	14	Competitive soccer, recreational swimming	Soccer	Soccer
U10	M	25	3	4	Weight training	Skateboarding	Snowboarding, biking
S1	M	28	NA	NA	Recreational football	NA	NA
S2	M	21	NA	NA	Competitive baseball	NA	NA
S3	M	23	NA	NA	Weight training	NA	NA
S4	F	24	NA	NA	None	NA	NA
S5	M	24	NA	NA	Recreational golf, softball, weight training	NA	NA
S6	F	21	NA	NA	None	NA	NA
S7	M	20	NA	NA	Recreational tennis, weight training, biking	NA	NA
S8	F	29	NA	NA	Recreational badminton, racquetball, weight training	NA	NA
S9	M	29	NA	NA	Recreational volleyball, weight training	NA	NA
S10	M	25	NA	NA	Recreational running, weight training	NA	NA
S11	M	23	NA	NA	Recreational football, basketball	NA	NA
S12	F	21	NA	NA	Recreational kickboxing, soccer	NA	NA
S13	M	21	NA	NA	Weight training	NA	NA
S14	M	27	NA	NA	Recreational basketball, weight training	NA	NA
S15	M	39	NA	NA	Recreational running	NA	NA

[a] M=male, F=female, NA=not applicable.

with only partial dislocation or subluxation also were excluded from the study. Participants with unstable shoulders were recruited from the local university medical center, and only those with a proper diagnosis were invited for further screening.

More individuals with healthy shoulders than individuals with anterior shoulder instability were recruited to properly establish control performance. Because a person's sex[32] and age[11,33,34] may have an impact on joint position sense, participants with a similar sex ratio and age range were recruited for both the control group and the experimental group. Inclusion criteria for the control group included no known history of shoulder injury that required medical treatments and the ability to move the shoulders to the target positions without discomfort or limitations. Participants with healthy shoulders were recruited from the local university student body and staff. Based on the pilot data of 6 individuals (3 with unstable shoulders and 3 with healthy shoulders), the sample size of 10 participants in the experimental group was considered adequate to detect group differences with a power of 80% when the significance level is .05.

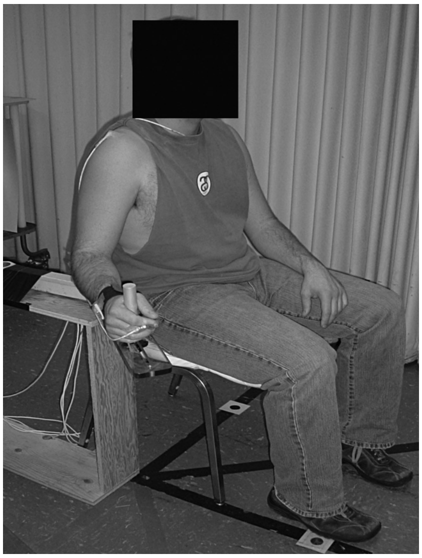

Figure 1.
Passive matching. The blindfolded participant rested his arm on the movable arm of the manipulandum, which was moved by the experimenter to the target angle (in this case, 45° of external rotation).

Figure 2.
Active rotation. The blindfolded participant actively moved his unsupported arm to the target angle (in this case 45° of external rotation, with 90° of abduction).

Measures

The Ascension Technology miniBIRD (MB) electromagnetic tracking system (Ascension Technology Corp, Burlington, Vermont) was used to record shoulder kinematics (74-Hz sampling rate). Five electromagnetic receivers of the MB system were secured on the skin over each participant's manubrium, the distal end of the scapular acromion, the lateral epicondyle of the humerus (on the brace over the lateral epicondyle for active positioning testing), the wrist cuff over the styloid process of the ulna, and the tip of the index finger. Data from the index finger sensor were used for recording end-point accuracy of 3-dimensional reaching movements, which will be reported in a future manuscript.

A custom-made Plexiglas manipulandum consisting of a movable arm that rotates in the horizontal plane on a stationary vertical axis (with minimal friction) under the elbow joint center was used for passive matching testing (Fig. 1). The adjustable handle location on the manipulandum was designed to ensure a comfortable grip with the participant's wrist in its neutral position. A flat piece of cardboard marked with the target angles was positioned under the manipulandum during testing to provide visual cues to the experimenter for the intended targets. To better represent humerus movements during active positioning testing, the elbow of the examined arm was placed in a padded brace with 90 degrees of elbow flexion and neutral forearm rotation, and the humeral receiver was placed on the brace over the lateral epicondyle of the humerus (Fig. 2). Participants were blindfolded and sat in an armless chair with a vertical back support during all testing procedures.

Procedure

After giving their consent, all potential participants first attended a screening session (the first visit) prior to the data collection phase of the study. The primary investigator (Y.H.) first examined whether participants could reach to all predetermined target angles freely with both arms without limitation, pain, or apprehension. Second, the primary investigator applied MMT to examine whether the participants had muscle weakness of their shoulder external and internal rotators and flexors and abductors. Before the second visit, participants were instructed to avoid strenuous or repetitive upper-extremity activities at least 1 day prior to the scheduled testing to avoid muscle fatigue and discomfort. The 3 testing protocols (passive matching, active rotation, and active abduction) were conducted in random order, and participants took at least a 1-minute break between protocols. Prior to each testing protocol, blindfolded participants were positioned at 0 degrees of shoulder abduction, 0 degrees of shoulder rotation, and 90 degrees of shoulder flexion as measured with a goniometer, and shoulder angles were recorded with the MB system in this position. The end position of all following trials was compared with this aligned position to determine their shoulder angles.

For passive matching, blindfolded participants were instructed to relax the tested arm and place the ulnar surface of the forearm on the movable arm of the manipulandum with the elbow placed over the rotational axis on the manipulandum (Fig. 1). The height and handle location of the manipulandum were further adjusted according to each individual's body dimensions. The primary investigator first explained the testing procedures to the participants, and then they practiced 3 to 5 trials to some random angles while blindfolded. Without informing the participants of the intended target locations, the primary investigator first moved the forearm (by moving the handle) in the horizontal plane to rotate the shoulder toward 1 of the 3 target shoulder rotation angles (45° of internal rotation [IR], 45° of ER, and 75° of ER). Seventy-five degrees of ER was chosen to represent the end-range of motion for passive testing because most participants (including those with healthy shoulders) could not externally rotate to 90 degrees when rotating the forearm in the horizontal plane with a small abduction angle. After staying at the target for 3 seconds to enable the participant to remember the target location, the examiner moved the shoulder to a new position, which was approximately 15, 30, 45, or 60 degrees rotated away from the original target location in either direction. All participants were repositioned away with the same rotational angles (15°, 30°, 45°, or 60°) but not in the same pseudo-random order.

The starting position for the reproduction phase was varied to emphasize the target position and discourage the participants from remembering the amplitude and time used to reach to the target as a cue in reproducing the target angle. Subsequently, the investigator moved the forearm slowly back toward the previous (remembered) target angle, and participants were instructed to say "stop" when they felt they had been returned to the remembered target location. The participants could request to rotate the shoulder back in the opposite direction if they felt that the examiner had overshot the target. The participants performed 8 trials for each target (3 targets in total) in a random order.

For active abduction, the primary investigator first described the testing procedures and the spatial definition of 3 easily comprehended angles (45°, 90°, and 135° of shoulder abduction in the frontal plane) before demonstrating the task for the participants. In order to avoid use of visual feedback to remember the designated target location during practice, participants were not allowed to practice during the investigator's demonstration and practiced only while blindfolded later without receiving position accuracy feedback from the investigator. After being given the target location verbally for a specific trial, blindfolded participants actively moved the examined shoulder from the starting position to the target position with a comfortable speed. After staying at the target location for 1 second, participants then returned the arm to its starting position and were encouraged to relax the shoulder after each trial. Participants performed 8 trials for each target (for a total of 24 trials) in a random order.

For active rotation, the same demonstration and practice protocols as in active abduction testing were implemented. After being given the target location verbally for a specific trial, participants first actively moved the shoulder to approximately 90 degrees of abduction and then to one of the 3 shoulder rotation angles (45° of IR, 45° of ER, or 90° of ER) with a comfortable speed (Fig. 2). After staying at the target location for 1 second, they then returned the arm to its starting position. Participants performed 8 trials for each target in a random order for a total of 24 trials. All 25 individuals participated in active abduction and rotation protocols. However, 2 individuals with healthy shoulders and 3 with unstable shoulders were not able to participate in the passive matching protocol due to time limitations or inability to position the arm to 45 degrees of IR (blocked by the trunk).

Data Analysis

Skill Technologies' 6D Research software (Skill Technologies Inc, Phoenix, Arizona) was used to compute positions and orientations of the MB receivers, and a custom-design program converted the data to a format that was further analyzed with DataPac 2K2 software (Run Technologies, Mission Viejo, California). Humerus orientation was computed relative to the trunk coordinate system, which was positioned parallel to the global coordinate system. In order to reduce humerus orientation measurement errors caused by the potential movement of the humerus receiver, shoulder rotation and abduction angles were computed by constructing a local humeral coordinate system followed by 3 ordered rotations about axes fixed to the humerus. Absolute position data from 3 noncollinear points (acromion, elbow, and wrist receivers) were used to construct a local coordinate system for the humerus. The orientation of the humerus then was calculated by relating the local humerus coordinate system to the global system with a series of ordered rotations about the humeral axes: vertical axis (defines yaw angle), medial-lateral axis (defines elevation angle), and long axis of the humerus (defines IR/ER angle).

For passive matching, shoulder rotation angles obtained in the matching

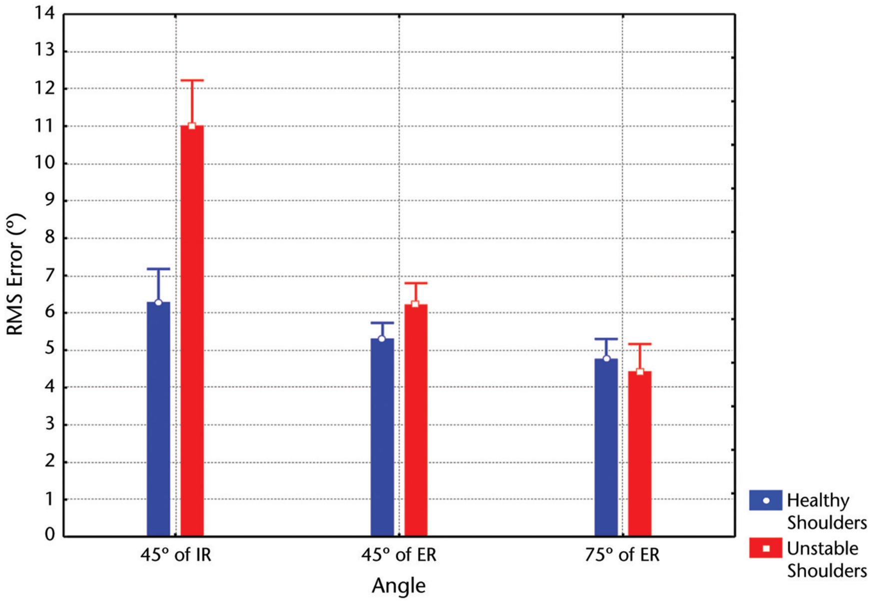

Figure 3.
Mean root mean square (RMS) errors of participants with healthy shoulders and participants with unstable shoulders at 3 different shoulder rotation angles (45° of internal rotation [IR], 45° of external rotation [ER], and 75° of ER) in the reproduction of shoulder rotation angles with passive matching. Error bars denote 1 standard deviation.

trial were compared with the target rotation angles positioned earlier by the primary investigator in the initial trial. For active abduction and rotation, the shoulder angle perceived by the participant at the target location was compared with the specific target angle given to the participant. The root mean square (RMS) errors, which combined both the constant and variable errors, were computed to represent the overall positioning errors for group comparison.

Two-way analysis of variance (ANOVA) with one between-group factor (unstable versus healthy shoulders) and one repeated-measures factor (3 target positions) was used to analyze the data for passive matching and active abduction and rotation testing. The Tukey honestly significant difference test was used for *post hoc* testing of significant main and interaction effects. Because there were 3 levels (3 targets) for the repeated-measures factors, adjustments in degrees of freedom using Greenhouse-Geisser correction were applied. Significance level (*P* values) was set at .05 for all comparisons. All analyses were conducted using Statistica (StatSoft Inc, Tulsa, Oklahoma).

Results

For passive matching, participants with unstable shoulders exhibited significantly larger overall RMS errors than those with healthy shoulders ($F_{1,18}$=4.64, P<.05, Fig. 3). Target location (shoulder rotation angle) affected the repositioning accuracy, and the group difference depended on target angles, as there were significant angle ($F_{2,36}$=22.17, P<.01) and group × angle interaction effects ($F_{2,36}$=8.85, P<.01). *Post hoc* tests showed participants in both groups made greater errors when matching the target angle near 45 degrees of IR compared with the other 2 angles (45° of ER and 75° of ER). At 45 degrees of IR, RMS errors for unstable shoulders were significantly larger than errors for healthy shoulders. At 45 and 75 degrees of ER, RMS errors for unstable shoulders were not different from errors for healthy shoulders. Despite the significant group effect, it is important to note that the overall group difference was relatively small (1.8°) and unstable shoulders showed significantly larger errors than healthy shoulders near 45 degrees of IR (group difference of 4.7°) but not at the other 2 ER angles.

For active abduction, participants with unstable shoulders actively moved the free arm to 3 different verbally instructed abduction angles (45°, 90°, and 135°) as accurately as participants with healthy shoulders ($F_{1,23}$=0.69, P>.41, Fig. 4). However, target shoulder abduction angle had a significant impact on shoulder positioning accuracy ($F_{2,46}$=11.41, P<.01), which was similar for both groups, as there was no significant angle × group interaction effect ($F_{2,46}$=0.49, P>.56). *Post hoc* comparison showed participants made significantly greater errors when moving their shoulders to 45 and 135 degrees of abduction than to 90 degrees of abduction.

For active rotation, participants with unstable shoulders internally and externally rotated the humerus to the 3 verbally instructed target locations as accurately as participants with healthy shoulders ($F_{1,23}$=1.16, P>.29, Fig. 5). In all 3 target positions, RMS errors for unstable shoulders were not different from those for healthy shoulders. Positioning accuracy was similar for the 3 target shoulder rotation angles ($F_{2,46}$=2.50, P>.10), and both groups responded similarly to the 3 target angles, as there was no significant group × angle interaction, although there was a trend ($F_{2,46}$=2.66, P>.09). Participants with unstable shoulders showed slightly larger RMS errors than those with healthy shoulders near the end-range of shoulder rotation (90° of ER), but smaller errors near the other 2 rotation angles. Moreover, it is worth noting that participants in both groups exhibited the smallest position errors at 45 degrees of ER where shoulder stabilizers were not greatly stretched.

Discussion

Passive Matching

Individuals with a history of anterior shoulder dislocation exhibited joint position sense deficits when examined with a technique that involved reproduction of remembered shoulder rotation angles with imposed motion of the supported arm. This finding is consistent with previous findings that unstable shoulders exhibited joint position sense deficits with passive matching.[9,12–14] Because activation of joint capsule receptors is triggered by the deformation and changing of tension of the structures that stabilize the joint, overstretched shoulder capsules and ligaments may contribute to the observed joint position sense deficits. More importantly, compromised mechanoreceptors of shoulder muscles probably contribute to the deficits as well. Because participants were instructed to relax the supported arm during reproduction of shoulder rotation angles, spindles were less sensitive due to fusimotor activation and GTOs were less activated due to low muscle tensions.[15,19,35–38] Moreover, greater-than-normal anterior-inferior translation of the humeral head has been observed in people with anterior instability during passive movement.[7,39] Because shoulder rotator cuff muscles insert into the humeral head, altered humeral head location due to instability may change the length of shoulder muscles and, therefore, the perceived shoulder rotation angles.

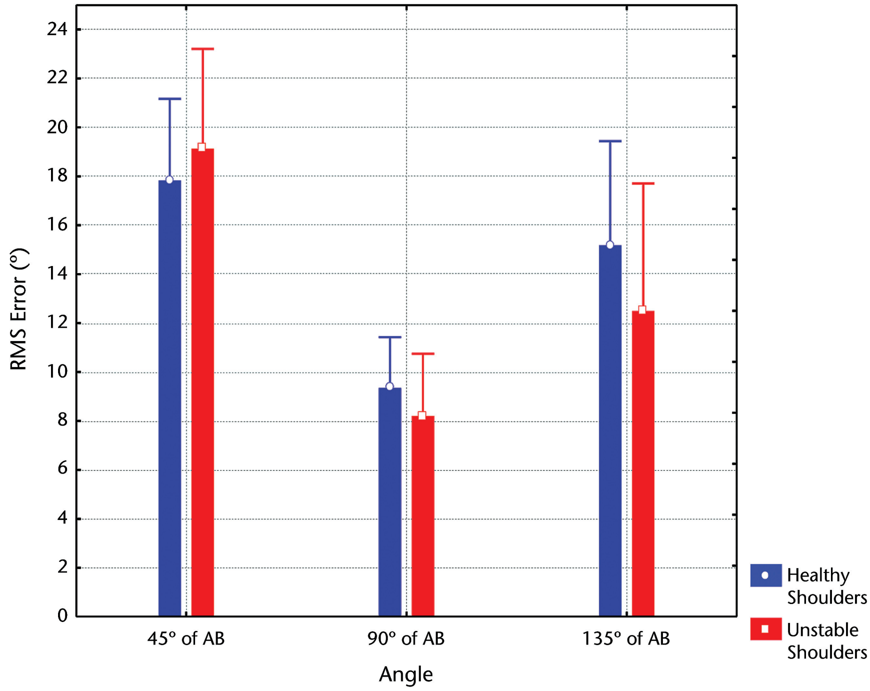

Figure 4.
Mean root mean square (RMS) errors of participants with healthy shoulders and participants with unstable shoulders at 3 different shoulder abduction (AB) angles (45°, 90°, and 135° of abduction) with active abduction. Error bars denote 1 standard deviation.

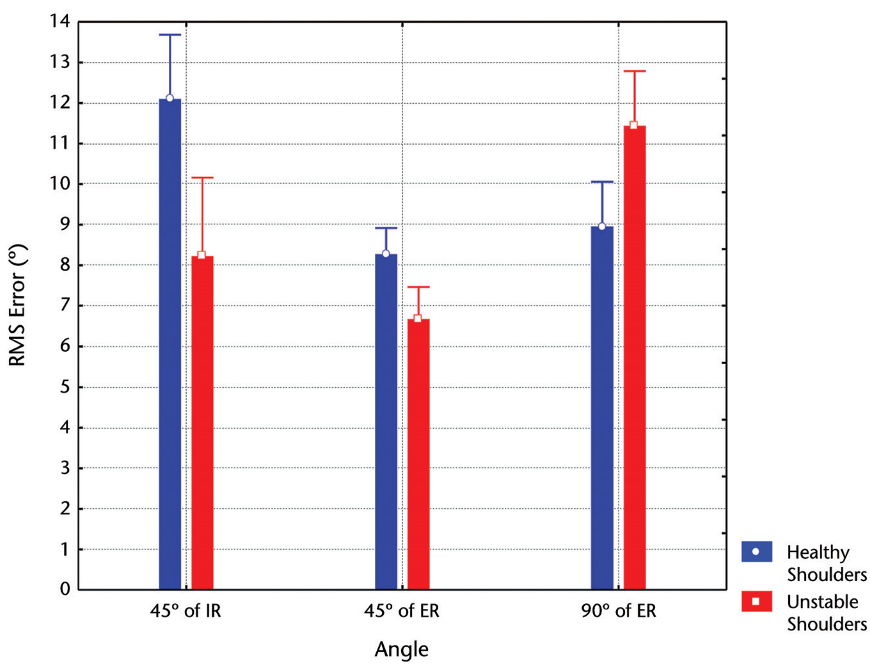

Figure 5.
Mean root mean square (RMS) errors of participants with healthy shoulders and participants with unstable shoulders at 3 different shoulder rotation angles (45° of internal rotation [IR], 45° of external rotation [ER], and 90° of ER) with active rotation. Error bars denote 1 standard deviation.

One unexpected finding of passive matching was that participants with unstable shoulders exhibited significantly larger errors than those with healthy shoulders only near 45 degrees of IR, not at the 2 ER angles. As previously described, receptors of shoulder muscles may be less capable of providing accurate joint position sense without voluntary motion and without a stable humeral head position in people with unstable shoulders. Without additional joint position sense information from joint receptors (due to stretching), muscle receptors may be less capable of providing accurate joint position sense near 45 degrees of IR in a relaxed condition. Moreover, the group difference at 45 degrees of IR of the present study (4.7°) is larger than the differences found in other studies that examined the intermediate range of shoulder rotation (0.6°–2.3°).[9,12,13] One likely explanation for the smaller group difference in earlier joint position sense studies is that the initial trial and the following matching trial often had the same starting position and range of motion and the same machine-controlled movement speed (except for the study by Lephart et al,[9] who varied the speed between the 2 trials). Therefore, participants in earlier studies might have used the time to reach the target as an additional cue to improve shoulder angle perception, whereas this cue was not available in the present study due to variations in starting joint angle and movement speed.

The magnitude (1.8° overall group difference) and nature (most prominent near 45° of IR) of the joint position sense deficits observed in participants with unstable shoulders may not have a significant impact on daily activities at a functional level. Despite the significant overall group effect in RMS errors, it is important to note that the differences between groups were small in 2 of the 3 target angles for the present study (0.3° difference at 75° of ER and 0.9° difference at 45° of ER) and in previous studies (0.6°–2.3°).[9,12,13] Considering that the GHJ is most vulnerable near the end-range of ER in people with anterior instability, the results of this investigation show that both individuals with unstable shoulders and those with healthy shoulders have similar joint position sense at a vulnerable position (75° of ER) at which anterior dislocations often occur.

During passive matching, participants were asked to fully relax while being moved to various rotation angles. However, as in previous studies,[9,12–14] it is unknown how much shoulder muscle activation actually occurred, especially toward the end-range of ER where the GHJ is least stable. Although it is more appropriate to describe the protocol as an "imposed movement" condition, to be consistent with the literature, we used the terminology of "passive matching" in the present study.

We examined both shoulder abduction and rotation with the active positioning protocol. However, passive abduction was not tested in our study. The main reason for conducting passive matching was to have data of a commonly used protocol to compare with data from a novel active positioning protocol. Because shoulder ER may impose a higher risk than shoulder abduction for people with anterior shoulder instability, in line with prior passive matching studies,[9,12] only passive rotation was conducted in this study.

Active Abduction and Active Rotation

For active abduction, participants with unstable shoulders actively moved the examined shoulder to the 3 instructed abduction angles (45°, 90°, and 135°) as accurately as the participants with healthy shoulders, with a group difference of 0.85 degrees in RMS errors. No previous study examined shoulder position sense with this testing protocol. However, the results of this study are consistent with those of studies that required participants to "actively" move their shoulders to match a remembered target,[28,31] although without requiring memory of a target in the present work. For active rotation, participants with unstable shoulders also moved their shoulders to the 3 targets (45° of IR, 45° of ER, and 90° of ER) as accurately as the participants with healthy shoulders, with a group difference of 0.99 degrees in RMS errors. These findings agree with the hypothesis of this investigation that people with a history of anterior shoulder dislocation would not exhibit joint position sense deficits when examined with an active testing protocol that better resembles functional activities than passive matching.

With accurate awareness of shoulder orientation, people with unstable shoulders may be able to position the shoulder to a desired location for daily activities, as well as exert proper shoulder muscle activation to stabilize the GHJ when moving toward vulnerable positions. As described in the "Discussion" section for passive matching testing, this result could be due to enhanced mechanoreceptor information with voluntary muscle contraction. In addition, researchers have found that anterior translation of the humeral head was reduced such that it was in a more centered or normal location within the glenoid fossa with active shoulder abduction and rotation.[7,23–27] With proper muscle length information, individuals with unstable shoulders were able to perceive shoulder joint angle as accurately as those with healthy shoulders in the current study.

The accuracy of perception of shoulder abduction angles depended strongly on the shoulder abduction angle. The results show that both groups exhibited the largest errors at 45 degrees of abduction and the smallest errors at 90 degrees of abduction. Although no study previously examined shoulder position sense with the same protocol, other studies found better joint position sense when shoulder flexion and abduction angles approached 90 degrees.[28,40] One explanation for the more accurate joint position sense near 90 degrees of abduction is that the upper limb generates the largest gravitational torque at 90 degrees and, therefore, requires greater muscle force or effort from shoulder abductors to achieve the position. As discussed earlier, better sensation of joint angles as well as a better stabilized humeral head may contribute to the observed superior joint position sense at 90 degrees due to the necessary stronger muscle contractions. Moreover, less shoulder position error at 90 degrees of abduction may be due to individuals being more familiar with and capable of aligning the upper limb to earth fixed horizontal than other orientations.[41,42] On the other hand, both groups had the largest position errors at 45 degrees of abduction where less abductor muscle force is needed and both active and passive shoulder stabilizers are stretched less than at 90 and 135 degrees of abduction. Thus, both muscle receptors and joint receptors may be less sensitive in providing shoulder position sense near 45 degrees of abduction than at greater abduction angles.

The accuracy of the perception of shoulder rotation angles did not depend on the rotation angle. Participants with unstable shoulders exhibited the largest errors at 90 degrees of ER, but these errors were not significantly larger than those of the participants with healthy shoulders at this critical position. One possible explanation is that enhanced muscle spindle sensitivity and a more centered humeral head with the active positioning protocol may compensate for joint position sense deficits caused by compromised joint receptors. Despite the lack of significant difference between the 2 groups at 90 degrees of ER, participants with unstable shoulders exhibited the largest position errors at this vulnerable position. Clinicians who implement joint position sense training should focus on this position because shoulder position sense is clearly accurate at other positions for individuals with unstable shoulders.

The RMS errors in active rotation were usually larger than the errors in passive rotation. This finding probably was due to the different natures of the tasks. Passive matching is a simple, 1-dimensional task in which individuals only have to pay close attention to match the perception of the remembered location (not necessarily the angle in degrees they actually perceive). In addition, more tactile information was available (at the elbow support) during the task, which might further enhance "matching" accuracy. Active positioning is a 3-dimensional task in which the participants moved their unsupported arms to a verbally specified configuration in space. They were able to comprehend the described arm positions, but positioning the arm would depend on an internal perceived estimate of the specified arm position. Also, some locations (eg, 90° of abduction with 45° IR) are not commonly used on a daily basis, which might be expected to produce larger errors. Additional analysis of variable errors showed that participants in both groups consistently positioned the arm to approximately 45 degrees of IR during both active rotation (3.8° in the control group versus 4.2° in the experimental group) and passive rotation (3.1° in the control groups versus 4.9° in the experimental group), suggesting that the higher RMS errors in active positioning were due primarily to the perceived nature of the task.

Conclusions

The purpose of this investigation was to determine whether individuals with a history of anterior shoulder dislocation exhibited joint position sense deficits compared with individuals with healthy shoulders. This study examined shoulder position sense at both the mid-range and end-range of shoulder motion with passive matching and active positioning protocols. The results showed that people with unstable shoulders can perceive shoulder angles as accurately as people with healthy shoulders in activities involving voluntary arm movements. These observations suggest that altered neuromuscular control due to compromised shoulder position sense may not be the main contributor to recurrent shoulder dislocations. Other factors (eg, compromised passive stabilizers, returning to an active lifestyle and sports) may be more important contributors to recurrent shoulder instability than joint position sense deficits. Moreover, the effectiveness of implementing proprioceptive training to enhance neuromuscular coordination to improve dynamic stability for unstable shoulders[10,43,44] should be further examined.

Limitations

The majority of the participants with unstable shoulders (9 out of 10) and those with healthy shoulders (13 out of 15) regularly participated in recreational or competitive activities. It is not clear whether a person's fitness level would have an impact on shoulder perception. Although young, athletic individuals have the highest recurrence rate for shoulder dislocation,[45] the results of the current study may not be generalized to all individuals (in different age groups or fitness levels) with anterior shoulder instability or those with other types of instability (eg, multidirectional instability).

In order to have participants with the greatest position sense deficits in comparison with those with healthy shoulders, we recruited only individuals with a proper diagnosis from a university medical center and excluded those with only partial dislocation or subluxation. These criteria greatly limited the number of participants for our experimental group. Although our sample size was adequate based on the power analysis, further investigation with a larger sample size may be beneficial.

Both authors provided concept/idea/research design, writing, and data analysis. Dr Hung provided data collection, project management, and participants. Dr Darling provided facilities/equipment and consultation (including review of manuscript before submission).

This study was approved by the Institutional Review Board of the University of Iowa.

An abstract of this research was presented at the annual conference of the Society for Neuroscience; November 13–17, 2010; San Diego, California.

DOI: 10.2522/ptj.20110236

References

1 Liu SH, Henry MH. Anterior shoulder instability: current review. *Clin Orthop Relat Res.* 1996:327–337.

2 Mahaffey BL, Smith PA. Shoulder instability in young athletes. *Am Fam Physician.* 1999;59:2773–2782, 2787.

3 Simonet WT, Cofield RH. Prognosis in anterior shoulder dislocation. *Am J Sports Med.* 1984;12:19–24.

4 Brenneke SL, Reid J, Ching RP, Wheeler DL. Glenohumeral kinematics and capsuloligamentous strain resulting from laxity exams. *Clin Biomech (Bristol, Avon).* 2000;15:735–742.

5 Itoi E, Hsu HC, An KN. Biomechanical investigation of the glenohumeral joint. *J Shoulder Elbow Surg.* 1996;5:407–424.

6 Turkel SJ, Panio MW, Marshall JL, Girgis FG. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. *J Bone Joint Surg Am.* 1981;63:1208–1217.

7 von Eisenhart-Rothe RM, Jager A, Englmeier KH, et al. Relevance of arm position and muscle activity on three-dimensional glenohumeral translation in patients with traumatic and atraumatic shoulder instability. *Am J Sports Med.* 2002;30:514–522.

8 Davies GJ, Dickoff-Hoffman S. Neuromuscular testing and rehabilitation of the shoulder complex. *J Orthop Sports Phys Ther.* 1993;18:449–458.

9 Lephart SM, Warner JJ, Borsa PA, Fu FH. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. *J Shoulder Elbow Surg.* 1994;3:371–380.

10 Myers JB, Lephart SM. The role of the sensorimotor system in the athletic shoulder. *J Athl Train.* 2000;35:351–363.

11 Nyland JA, Caborn DN, Johnson DL. The human glenohumeral joint: a proprioceptive and stability alliance. *Knee Surg Sports Traumatol Arthrosc.* 1998;6:50–61.

12 Smith RL, Brunolli J. Shoulder kinesthesia after anterior glenohumeral joint dislocation. *Phys Ther.* 1989;69:106–112.

13 Zuckerman JD, Gallagher MA, Cuomo F, Rokito A. The effect of instability and subsequent anterior shoulder repair on proprioceptive ability. *J Shoulder Elbow Surg.* 2003;12:105–109.

14 Rokito AS, Birdzell MG, Cuomo F, et al. Recovery of shoulder strength and proprioception after open surgery for recurrent anterior instability: a comparison of two surgical techniques. *J Shoulder Elbow Surg.* 2010;19:564–569.

15 Gandevia SC, McCloskey DI, Burke D. Kinaesthetic signals and muscle contraction. *Trends Neurosci.* 1992;15:62–65.

16 McCloskey DI. Kinesthetic sensibility. *Physiol Rev.* 1978;58:763–820.

17 Suprak DN, Osternig LR, van Donkelaar P, Karduna AR. Shoulder joint position sense improves with external load. *J Mot Behav.* 2007;39:517–525.

18 Brindle TJ, Uhl TL, Nitz AJ, Shapiro R. The influence of external loads on movement precision during active shoulder internal rotation movements as measured by 3 indices of accuracy. *J Athl Train.* 2006;41:60–66.

19 Gandevia SC, McCloskey DI. Joint sense, muscle sense, and their combination as position sense, measured at the distal interphalangeal joint of the middle finger. *J Physiol.* 1976;260:387–407.

20 Cross MJ, McCloskey DI. Position sense following surgical removal of joints in man. *Brain Res.* 1973;55:443–445.

21 Gandevia SC, Smith JL, Crawford M, et al. Motor commands contribute to human position sense. *J Physiol.* 2006;571:703–710.

22 Walsh LD, Hesse CW, Morgan DL, Proske U. Human forearm position sense after fatigue of elbow flexor muscles. *J Physiol.* 2004;558:705–715.

23 Graichen H, Stammberger T, Bonel H, et al. Glenohumeral translation during active and passive elevation of the shoulder: a 3D open-MRI study. *J Biomech.* 2000;33:609–613.

24 Hsu HC, Boardman ND III, Luo ZP, An KN. Tendon-defect and muscle-unloaded models for relating a rotator cuff tear to glenohumeral stability. *J Orthop Res.* 2000;18:952–958.

25 Kido T, Itoi E, Lee SB, et al. Dynamic stabilizing function of the deltoid muscle in shoulders with anterior instability. *Am J Sports Med.* 2003;31:399–403.

26 Lee SB, Kim KJ, O'Driscoll SW, et al. Dynamic glenohumeral stability provided by the rotator cuff muscles in the mid-range and end-range of motion: a study in cadavera. *J Bone Joint Surg Am.* 2000;82:849–857.

27 Wuelker N, Korell M, Thren K. Dynamic glenohumeral joint stability. *J Shoulder Elbow Surg.* 1998;7:43–52.

28 Forwell LA, Carnahan H. Proprioception during manual aiming in individuals with shoulder instability and controls. *J Orthop Sports Phys Ther.* 1996;23:111–119.

29 Aydin T, Yildiz Y, Yanmis I, et al. Shoulder proprioception: a comparison between the shoulder joint in healthy and surgically repaired shoulders. *Arch Orthop Trauma Surg.* 2001;121:422–425.

30 Herrington L, Horsley I, Rolf C. Evaluation of shoulder joint position sense in both asymptomatic and rehabilitated professional rugby players and matched controls. *Phys Ther Sport.* 2010;11:18–22.

31 Potzl W, Thorwesten L, Gotze C, et al. Proprioception of the shoulder joint after surgical repair for instability: a long-term follow-up study. *Am J Sports Med.* 2004;32:425–430.

32 Bjorklund M, Crenshaw AG, Djupsjobacka M, Johansson H. Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. *Eur J Appl Physiol.* 2000;81:361–367.

33 Skinner HB, Barrack RL, Cook SD. Age-related decline in proprioception. *Clin Orthop Relat Res.* 1984:208–211.

34 Kaplan FS, Nixon JE, Reitz M, et al. Age-related changes in proprioception and sensation of joint position. *Acta Orthop Scand.* 1985;56:72–74.

35 Goodwin GM, McCloskey DI, Matthews PB. The contribution of muscle afferents to kinaesthesia shown by vibration induced illusions of movement and by the effects of paralysing joint afferents. *Brain.* 1972;95:705–748.

36 Lonn J, Crenshaw AG, Djupsjobacka M, et al. Position sense testing: influence of starting position and type of displacement. *Arch Phys Med Rehabil.* 2000;81:592–597.

37 Hulliger M, Vallbo AB. The responses of muscle spindle afferents during voluntary tracking movements in man: load dependent servo assistance? *Brain Res.* 1979;166:401–404.

38 Edin BB, Vallbo AB. Muscle afferent responses to isometric contractions and relaxations in humans. *J Neurophysiol.* 1990;63:1307–1313.

39 Hawkins RJ, Schutte JP, Janda DH, Huckell GH. Translation of the glenohumeral joint with the patient under anesthesia. *J Shoulder Elbow Surg.* 1996;5:286–292.

40 Jerosch J, Thorwesten L, Steinbeck J, Reer R. Proprioceptive function of the shoulder girdle in healthy volunteers. *Knee Surg Sports Traumatol Arthrosc.* 1996;3:219–225.

41 Darling WG, Hondzinski JM. Kinesthetic perceptions of earth- and body-fixed axes. *Exp Brain Res.* 1999;126:417–430.

42 Darling WG, Miller GF. Perception of arm orientation in three-dimensional space. *Exp Brain Res.* 1995;102:495–502.

43 Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med.* 1997;25:130–137.

44 Myers JB, Wassinger CA, Lephart SM. Sensorimotor contribution to shoulder stability: effect of injury and rehabilitation. *Man Ther.* 2006;11:197–201.

45 Wheeler JH, Ryan JB, Arciero RA, Molinari RN. Arthroscopic versus nonoperative treatment of acute shoulder dislocations in young athletes. *Arthroscopy.* 1989;5:213–217.

Physical Therapy
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Royal Dutch Society for Physical Therapy

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PHYS THER. 2012; 92:563-573.
Originally published online January 6, 2012
doi: 10.2522/ptj.20110236