J Shoulder Elbow Surg (2018) ■■, ■■–■■

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ORIGINAL ARTICLE

Bilateral shoulder proprioception deficit in unilateral anterior shoulder instability

Przemysław Lubiatowski, MD, PhD, DSc[a,b,*], Piotr Ogrodowicz, MD, PhD[a,b], Marcin Wojtaszek, MD[a], Leszek Romanowski, MD, PhD, DSc[a]

[a]*Department of Traumatology, Orthopaedics and Hand Surgery, University of Medical Sciences in Poznan, Poznań, Poland*
[b]*Rehasport Clinic, Poznań, Poland*

Hypothesis and background: Proprioception is an important element of shoulder dynamic stability. It has been shown to be affected in cases of capsular or labral injuries of the glenohumeral joint. Therefore, this study was conducted to investigate bilateral shoulder proprioception by active reproduction of joint position both in patients with post-traumatic recurrent unilateral shoulder instability and in normal healthy volunteers.
Methods: We compared 41 patients, comprising 11 female and 30 male patients with an average age of 25.6 years (range, 18-39 years), with post-traumatic unilateral anterior shoulder instability with a control group of 27 healthy volunteers with no history of shoulder problems and with normal shoulder function during examination. All patients were examined using a high-accuracy computer-controlled electronic goniometer (Propriometer). The error of active reproduction of joint position (EARJP) was measured in abduction, flexion, external rotation, and internal rotation in both shoulders.
Results: We observed a significant deficit in the EARJP in the unstable shoulders within the instability group. Surprisingly, similar results were recorded for the contralateral, unaffected shoulders within this group of patients compared with the control group. Joint acuity increased with higher elevation of the arm position.
Conclusion: Unilateral shoulder injuries, resulting in instability, affect proprioception in both shoulders, as demonstrated by an increased EARJP. This is the first report of unilateral shoulder instability coexisting with inferior proprioception in both shoulders.
Level of evidence: Basic Science Study; Kinesiology

Keywords: Proprioception; joint position sense; shoulder instability; shoulder injury; neuromuscular control; joint stability

The definition of "proprioception," as formulated by Goble,[20] refers to the ability of an individual to determine body segment positions and movements in space. Proprioception is based on sensory signals provided to the brain from muscle, joint, and skin receptors as a part of neuromuscular control of the body. This neuromuscular control may become dysfunctional when the nervous reflex is disrupted, which might be reflected in impaired proprioception.

This study was approved by the Bioethical Committee of the University of Medical Sciences in Poznań (962/11).

*Reprint requests: Przemysław Lubiatowski, MD, PhD, DSc, Department of Traumatology, Orthopaedics and Hand Surgery, University of Medical Sciences in Poznan, ul 28 Czerwca 1956r 135, Poznań 62-545, Poland.
E-mail address: p.lubiatowski@rehasport.pl (P. Lubiatowski).

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2018.08.034

Clinically, the relationship between injuries and impaired proprioception has been widely studied in lower-extremity pathologies.[9,11,42,49] Several studies, including a recent meta-analysis,[18] have shown impaired proprioception in patients with shoulder injuries, such as glenohumeral instability or shoulder impingement syndrome.[3,12,27,41,52] Because of its vast mobility, the shoulder joint is inherently unstable, relying heavily on the synchronicity of its active and passive structures for dynamic neuromuscular control. Joint position sense (JPS) for the shoulder has been tested with several different methods, in which an error between a presented target position and the ability to reproduce this position represents the accuracy of JPS.[28,54,60,64] Motion in different planes has been used to test shoulder JPS, including internal and external rotation,[28,54,56] elevation in different planes,[60,64] and functional movements.[7,63] Because most functional activities involve muscle contraction, active joint position reproduction and sense may better represent the afferent input necessary for functional activities.[60] Elevation may be a more appropriate protocol for representing functional activities, as internal and external rotation mainly comes from the glenohumeral joint and is not as functional a movement for the general population.[38]

The clinical significance of proprioception in the pathogenesis of shoulder instability has been demonstrated, with reports describing injury-related proprioception disorders[4] and a recovery of the proprioceptive capabilities after surgical reconstruction.[18,48] However, results described in the literature frequently have not taken into consideration contralateral shoulder proprioception. We hypothesized that unilateral shoulder instability would be associated with deficiency in ipsilateral shoulder JPS and inferior proprioception compared with the normal shoulder in the healthy population. We also assumed that joint acuity would be better with higher deviation from the neutral position. Therefore, this study was conducted to investigate bilateral shoulder proprioception by active reproduction of joint position both in patients with a diagnosis of post-traumatic recurrent unilateral shoulder instability and in normal healthy volunteers. A secondary objective was to assess the correlation of JPS with the angle of the tested arm position.

Materials and methods

The study was performed based on 41 patients with unilateral anterior traumatic shoulder instability (instability group) and 27 healthy volunteers, serving as the control group. All the patients signed an informed consent form. The instability group consisted of 11 female patients (average age, 27.1 ± 6.4 years) and 30 male patients (average age, 25.0 ± 5.4 years) with traumatic shoulder instability. Patients were qualified for the study based on the following criteria: (1) medical history of at least 2 anterior unilateral shoulder dislocations or subluxations, the first of which was traumatic, and (2) examination findings showing unilateral involvement, unilateral apprehension, normal range of motion, and a confirmed Bankart lesion during arthroscopy. Patients with generalized joint laxity (based on the Beighton score), rotator cuff tears, significant bony deformity (fracture, tumor, osteoarthritis, or severe deficit of glenoid or proximal humerus), or neurologic disorders were excluded from the study.

The control group consisted of 27 healthy volunteers: 17 female volunteers (average age, 24.0 ± 2.0 years) and 10 male volunteers (average age, 23.6 ± 2.3 years). Subjects were qualified for the study based on the following criteria: (1) medical history with no shoulder trauma or chronic pain, (2) examination findings showing no shoulder abnormalities or signs of laxity, and (3) age of 30 years or younger.

None of the study participants was a professional athlete of any kind. No significant age difference was recorded between the instability and control groups or between the sexes in either group.

Proprioception measurements

Shoulder proprioception measurements were performed using a high-accuracy computer-controlled electronic Propriometer (Progress, Ostrów Wielkopolski, Poland),[39,40] previously developed by our group. The system consists of an electronic goniometer (accuracy of 0.1°) and software that allow for precise measurement control, as well as proper data management.

To provide standardized, reproducible conditions (eg, to eliminate the impact of external factors such as noise or movement), all proprioception tests were performed in a dedicated testing room. Subjects used a modified rehabilitation couch (Technomex, Gliwice, Poland) (Fig. 1). Modifications were introduced in the back support

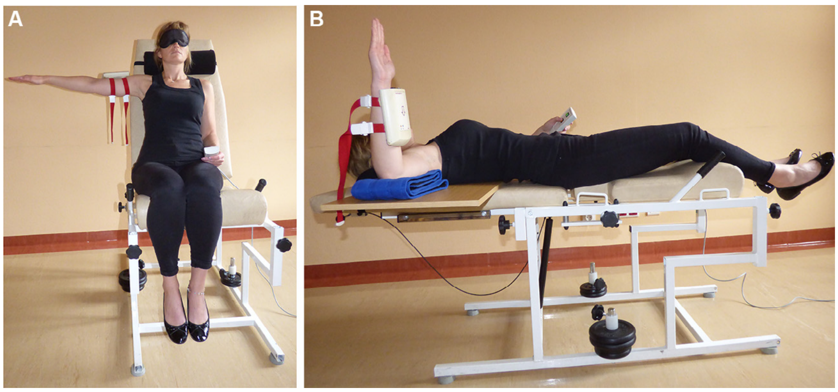

Figure 1 Patient and device (Propriometer) setup for evaluation of shoulder joint position reproduction for abduction of 90° **(A)** and rotation in neutral starting position **(B)**.

to allow for a sitting position test at a fixed back angle of 90° with respect to the seat, as well as a supine test with stabilization of the subject's posture. A pad was used to reduce the support surface of the shoulder and the contact of the subject's back with the backrest of the chair.

Proprioception evaluation

Before proprioception evaluation, the subjects performed standard shoulder warm-up exercises. To eliminate stimulation of the skin receptors, the patients' upper body was undressed to the waist with intimate zones covered. For the same reason, contact of the arm and shoulder with elements of the chair was minimized. To eliminate visual and vestibular signals during the test, the head and torso were immobilized and the eyes were covered (Fig. 1). The subjects were given practical knowledge regarding the testing procedure and were familiarized with the device. Shoulder proprioception was evaluated as the ability to reproduce a joint position. The protocol was based on a passive demonstration of the reference arm position followed by active reproduction of the position. The difference between the reference angle and the reproduced angle was determined as the error of active reproduction of joint position (EARJP).

EARJP was measured in 12 defined reference positions in both shoulders: flexion and abduction at 60°, 90°, and 120° and internal and external rotation at 30°, 45°, and 60° (Fig. 1). All measurements were repeated 5 times in each position. EARJP for every measurement was calculated as the absolute value of the difference between the demonstrated angle and reproduced angle. The mean EARJP value for each position was calculated from the 5 single measurements.

EARJP values within the control group were analyzed regarding the potential impact of sex, arm dominance, and extent of arm deviation from its neutral position on proprioceptive abilities. EARJP values within the instability patients were assigned to 1 of 2 subgroups: affected (unstable) shoulders and unaffected (stable) shoulders. Finally, the results were compared in several groups as follows: EARJP of the control group versus EARJP of stable shoulders within the instability group versus EARJP of unstable shoulders within the instability group.

Statistical analysis

Statistical analysis was conducted using the Statistica software program (version 8.2; StatSoft, Tulsa, OK, USA; www.statsoft.com). Normality testing was performed by the Shapiro-Wilk test. Because the distribution was not normal, nonparametric tests were subsequently used. The Mann-Whitney test was used to compare 2 independent samples (female patients vs male patients, dominant shoulder vs nondominant shoulder). Kruskal-Wallis analysis of variance (ANOVA) followed by the Dunn post hoc test was applied for multiple-group comparisons (3 reference positions, control group vs affected shoulders and unaffected shoulders in instability group), and the Spearman correlation index was used to assess the correlation between arm position angle and EARJP. The level of significance for all statistical analyses was set at $P < .05$.

Results

Influence of sex on EARJP values

A detailed analysis of EARJP values within the control group with respect to sex is presented in Table I. No significant differences were found when male participants versus female participants were compared for JPS. For this reason, all

Table I Average EARJP values with respect to sex within the control group

	EARJP value									
	30°		45°		60°		90°		120°	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ABD, °										
F					5.5	2.2	4.1	1.9	5.0	2.5
M					4.8	2.8	4.2	2.1	3.8	1.6
P value					.29		.91		.18	
FLX, °										
F					5.7	2.6	3.5	1.7	3.8	2.2
M					6.5	2.5	3.5	2.0	3.7	2.2
P value					.25		.79		.86	
ER, °										
F	3.2	1.4	2.8	1.3	3.2	1.4				
M	3.4	1.2	3.0	0.9	2.9	1.3				
P value	.59		.21		.33					
IR, °										
F	4.0	1.8	2.9	1.4	3.2	1.6				
M	3.8	1.6	3.4	1.4	2.9	1.4				
P value	.79		.23		.48					

EARJP, error of active reproduction of joint position; *SD*, standard deviation; *ABD*, abduction; *FLX*, flexion; *ER*, external rotation; *IR*, internal rotation; *F*, female; *M*, male.
P values are based on the Mann-Whitney test.

Table II Average EARJP values with respect to shoulder dominance within the control group

	EARJP value									
	30°		45°		60°		90°		120°	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ABD, °										
D					5.0	2.7	3.9	2.0	5.0	2.3
ND					5.0	2.8	4.3	1.8	3.9	1.6
P value					.29		.84		.42	
FLX, °										
D					5.9	2.8	3.1	1.6	3.9	2.5
ND					5.9	2.8	4.0	1.9	3.4	2.0
P value					.25		.76		.12	
ER, °										
D	3.6	1.5	3.1	1.0	3.0	1.3				
ND	3.1	0.9	2.9	1.1	3.2	1.6				
P value	.59		.21		.33					
IR, °										
D	3.6	1.4	3.1	1.2	2.9	1.4				
ND	4.1	1.9	3.2	1.7	3.1	1.6				
P value	.79		.23		.48					

EARJP, error of active reproduction of joint position; *SD*, standard deviation; *ABD*, abduction; *D*, dominant shoulder; *ND*, nondominant shoulder; *FLX*, flexion; *ER*, external rotation; *IR*, internal rotation.
P values are based on the Mann-Whitney test.

remaining analyses were performed without respect to sex and with the data for both sexes pooled.

Influence of shoulder dominance on EARJP values

A detailed analysis of EARJP values within the control group with respect to upper limb preference is presented in Table II. No significant differences were found when the dominant shoulder versus the nondominant shoulder was compared for JPS. For this reason, all remaining analyses were performed without respect to the side preference and with the data for both sides pooled.

Influence of arm position on EARJP values

The influence of arm deviation from the neutral testing position was evaluated based on pooled EARJP results (regardless of sex and shoulder dominance) (Fig. 2). The highest mean value of EARJP (lowest proprioceptive ability) was observed in the lowest tested angle in all directions of joint motion: abduction, flexion, internal rotation, and external rotation. However, significant differences were noted for flexion and internal rotation (Table III), both with Kruskal-Wallis ANOVA and the Spearman correlation coefficient. For both flexion and internal rotation, joint position matching improved with increased deviation from the neutral position.

Influence of shoulder instability on EARJP values

The average EARJP values for individual parameters within the unilateral post-traumatic joint instability group were divided into 2 subgroups: unstable shoulders and stable shoulders, irrespective of subject sex and limb dominance, as in the control group. The detailed results are presented in Figure 2. The average EARJP values in the control group were compared with the results measured in the instability group. Unexpectedly, we observed significant proprioception dysfunction in both unstable shoulders and stable shoulders within the instability group. Similarly inferior proprioception in both shoulders (compared with the control group) was observed during joint abduction and flexion at nearly all angles, as well as in external rotation at 45° and 60°. The most prominent example of reduced proprioception in both the affected and unaffected shoulders was recorded at 60° of abduction with the following EARJP values: 5.1° for the control group, 8.3° for stable shoulders, and 9.5° for unstable shoulders. We found no significant difference in joint position matching between the stable shoulders and unstable shoulders in the instability group in nearly all measured directions and arm positions (with the exception of internal rotation at 30°).

Moreover, we observed a clear reduction in the average EARJP values with an increasing angle of the tested position in abduction or flexion for unstable and stable shoulders in the instability group, which represents better joint acuity with a higher arm position (Tables IV and V). Kruskal-Wallis ANOVA with the Dunn post hoc test showed statistically significant differences in the EARJP values in joint abduction and flexion for unstable shoulders between angles of 60° and 90° ($P = .012$ and $P = .0004$, respectively), as well as between angles of 60° and 120° ($P = .002$ and $P = .005$, respectively). The observation was further confirmed when we looked at the correlation of EARJP with the angle of the

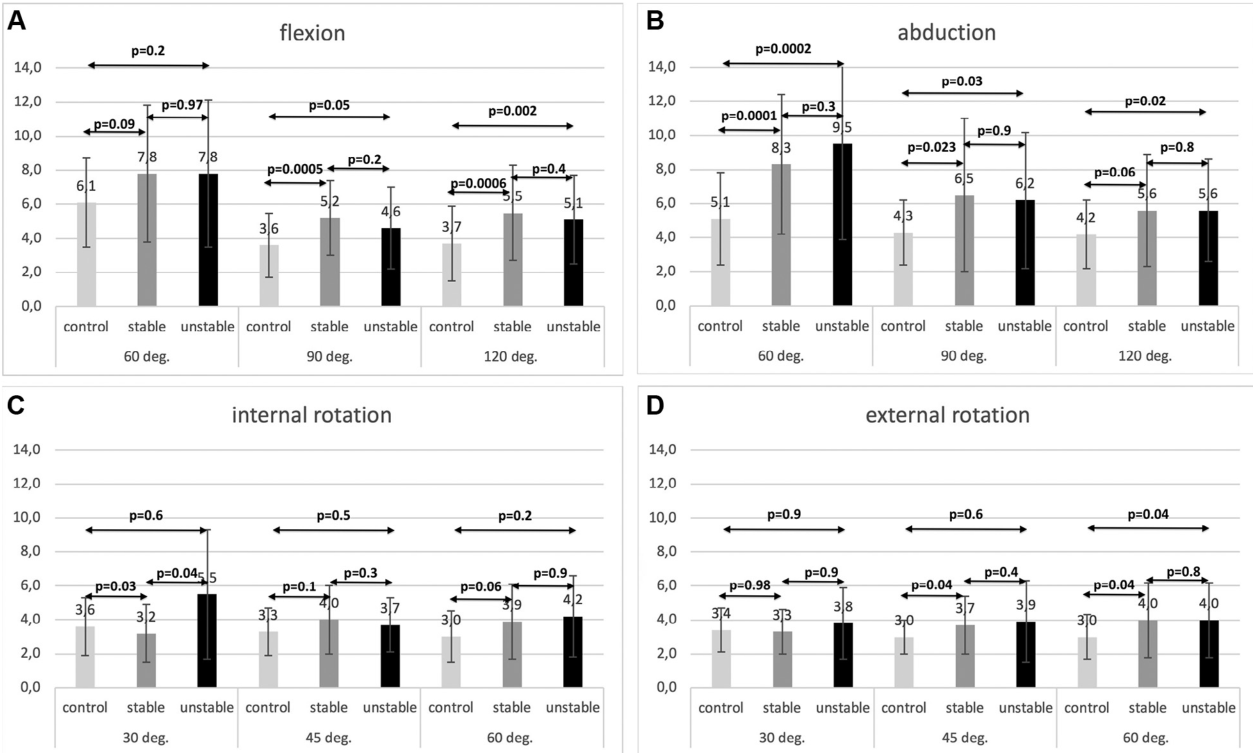

Figure 2 Results of error of active reproduction of joint position measured for control and instability groups in flexion (**A**), abduction (**B**), internal rotation (**C**), and external rotation (**D**). Average values for error of active reproduction of joint position, as well as *P* values (Kruskal-Wallis analysis of variance), are presented for the healthy control shoulders (control), contralateral shoulders in the instability group (stable), and affected shoulders in the instability group (unstable). *deg*, degrees.

Table III Statistical analysis of influence of angle of reference arm position on average EARJP values within the control group (sample comparison and correlation)

	P value						Spearman correlation coefficient/*P* value
	60° vs 90°	90° vs 120°	60° vs 120°	30° vs 45°	45° vs 60°	30° vs 60°	
ABD	.72	>.999	.45				$r = -0.12/P > .05$
FLX	.000001	>.999	.00008				$r = -0.39/P < .05$
ER				.49	>.999	.28	$r = -0.13/P > .05$
IR				.09	>.999	.008	$r = -0.25/P < .05$

EARJP, error of active reproduction of joint position; *ABD*, abduction; *FLX*, flexion; *ER*, external rotation; *IR*, internal rotation.
P values are based on the Kruskal-Wallis analysis-of-variance test.

reference arm position using the Spearman correlation index. For stable shoulders in the instability group, we found a significant negative correlation between EARJP and a higher flexion and elevation position of the arm (better acuity with a more elevated arm).

Discussion

By investigating active reproduction of the joint position at various angles and in various directions of shoulder movement, we found better joint acuity with an increase in the reference angle, represented by a significant decrease in the EARJP value. This correlation seems to be universal regardless of instability because it was found similarly in both groups. The observation has been supported by other studies, in which EARJP values were also higher (lower acuity) in the midrange than in the end range of the joint.[5,32,51,59] In the midrange, JPS is provided mainly by muscle mechanoreceptors, owing to the relative looseness of the joint capsule in this position compared with large variations in the muscle length.[43,45] In contrast, extending the range of joint motion close to its final range results in increased ligament and capsule tension and, as a consequence, might result in amplified afferentation from mechanoreceptors localized there. We found in our study only low variance regarding the proprioceptive capabilities among healthy volunteers. No significant mean differences were shown between the dominant and nondominant shoulders for any of the test conditions or between male and female

Table IV Statistical analysis of influence of angle of reference arm position on average EARJP values within instability group for unstable shoulder (sample comparison and correlation)

	P value						Spearman correlation coefficient/*P* value
	60° vs 90°	90° vs 120°	60° vs 120°	30° vs 45°	45° vs 60°	30° vs 60°	
ABD	.012	>.999	.002				*r* = −0.30/*P* < .05
FLX	.0004	>.999	.005				*r* = −0.30/*P* < .05
ER				>.999	>.999	>.999	*r* = 0.04/*P* > .05
IR				.36	>.999	.72	*r* = −0.12/*P* > .05

EARJP, error of active reproduction of joint position; *ABD*, abduction; *FLX*, flexion; *ER*, external rotation; *IR*, internal rotation.
P values are based on the Kruskal-Wallis analysis-of-variance test.

Table V Statistical analysis of influence of angle of reference arm position on average EARJP values within instability group for stable shoulder (sample comparison and correlation)

	P value						Spearman correlation coefficient/*P* value
	60° vs 90°	90° vs 120°	60° vs 120°	30° vs 45°	45° vs 60°	30° vs 60°	
ABD	.09	.09	.09				*r* = −0.28/*P* < .05
FLX	.12	.12	.12				*r* = −0.22 *P* < .05
ER				>.999	>.999	.9	*r* = 0.09/*P* > .05
IR				.26	>.999	.67	*r* = 0.12/*P* > .05

EARJP, error of active reproduction of joint position; *ABD*, abduction; *FLX*, flexion; *ER*, external rotation; *IR*, internal rotation.
P values are based on the Kruskal-Wallis analysis-of-variance test.

participants. This observation is consistent with previous reports.[8,33,41,53,64]

However, the most important part of the study and its findings is related to the issue of instability and proprioception. Numerous authors have hypothesized that a neurofeedback mechanism exists between afferent mechanoreceptors and muscular stabilizers and that disruption of this mechanism inhibits normal joint stability.[19,22,37,43,44,47,58,61,62] Indeed, patients with anterior instability have shown impaired proprioception in their unstable shoulders compared with their contralateral, uninjured limbs,[37,39] which was also shown in our study. However, our finding of significant deficiencies in EARJP in both shoulders in the instability group, when compared with the healthy control group, was unexpected. Moreover, we did not observe statistically significant differences between JPS values for both the stable and unstable shoulders within the instability group. Such a contralateral proprioception deficit for patients with unilateral traumatic anterior shoulder instability has not been reported so far. Finding the exact explanation for this phenomenon may be difficult, there is relatively limited amount of data for critical analysis. A few possible explanations can be postulated:

- Unilateral mechanoreceptor damage affecting central control
- Pre-existing proprioception deficits, leading to an increased risk of instability
- Limited activity due to shoulder instability, leading to a decreased overall proprioception ability
- Anxiety and behavioral factors affecting central neuromuscular control

The only study reporting bilateral proprioceptive deficits in unilateral shoulder disease is that of Sahin et al,[53] who showed that in patients with subacromial impingement syndrome, the proprioceptive impairment was observed not only in the involved shoulders but also in the uninvolved shoulders, when compared with the control group. However, the possible explanation has not been deeply discussed. The mechanism of proprioception and its deficit may be different in instability and impingement patients. In the first example, a clear association of joint sense and abnormal function of mechanoreceptors (due to tissue damage and loosening) has been proposed.[16,43] Painful conditions indicate that a central mechanism affects JPS. Some authors have suggested that proprioception may be mediated using pain as a protective indicator of danger or harm.[6,26,57] Instability is not typically a painful condition; however, it is associated with apprehension in the elevated arm position (especially abduction and external rotation). This leads to the signaling of the possibility of dislocation, which further results in discomfort. We have observed significant deficiencies in proprioception in unstable shoulders in positions corresponding to the strongest apprehension presented by patients during clinical examination. A recent series of studies on shoulder apprehension demonstrated changes in central neuronal processes based on functional magnetic resonance imaging.[23,67] When assessing sensorimotor areas of the brain, including the cortex, the authors found increased connectivity in a bilateral brain location in patients with unilateral shoulder apprehension.[23] They assumed that cognitive processes related to apprehension were generalized and independent from the side of shoulder instability. Moreover, Zanchi et al[67] stated that decreased proprioception may be a projection of cognitive and/or behavioral problems (anxiety related to fear of instability) and mirroring of function in bilateral problems. This is also supported by the study of Shitara et al[55] in which they postulated that patients may have so-called memory-induced shoulder apprehension. They used similar methodology (functional magnetic resonance imaging of the brain in shoulder instability) and found that patients without instability were able to imagine shoulder motion with more precision, vividness, and/or strength than were patients with instability. Although they examined only patients with right-sided problems, some bilateral increased activity of the brain could be noted. Insight into bilateral proprioception deficits was also given in a study on bilateral deficits of shoulder JPS in patients with chronic hemiparesis due to stroke.[13] The authors explained the bilateral decrease occurring during afferent processing and integration in the central nervous system. Some processing involves 2-sided structures (premotor cortical regions).

The contralateral proprioception deficits observed in this study might therefore suggest a disturbance of central neuromuscular control. Moreover, the examination was performed in an active mode, which included not only the sensory pathway but also the motor component, which is clearly under central control. Animal studies provided limited support for the thesis of unilateral damage leading to bilateral sense disturbance,[25] with pioneering work performed in cats in 1966.[17] Afferent stimulation failure, due to limb injury or immobilization, creates a reaction in both the ipsilateral and contralateral spinal centers, as a result of the function of the C3 and C4 propriospinal neurons.[2,46] Neurophysiological examination also showed activation at the same spine level in humans.[31] Decreased proprioception in unstable shoulders has been shown to improve significantly after labral repair and rehabilitation.[36,37,66,68] It is hypothesized that after repair, the joint and muscle receptors responsible for position sense and the ability to detect movement may be activated, which in turn may result in an improvement in neuromuscular control of the shoulder and restoration of reflex protective mechanisms. It will be interesting to observe whether proprioception normalizes in the studied cohort after successful surgery and rehabilitation and whether these issues affect both shoulders. This is the subject of an ongoing study.

Because proprioception plays a fundamental role in human movement control for daily activities, exercise, and sports, the importance of central processing in understanding proprioception has been especially recognized in recent years.[21,23,55,65] However, it is still vague whether an abnormal motion pattern appears as a result of shoulder instability or whether the shoulder dislocation occurs as a result of a previously occurring abnormal motion pattern and its control in the cerebral nervous system. Such a possibility has been claimed by Roberts et al,[50] who studied knee proprioception. They found a decreased proprioceptive ability not only in injured knees (unilateral anterior cruciate ligament reconstruction) but also in uninjured knees, as compared with healthy controls. Moreover, Koralewicz and Engh[35] found bilateral proprioception deficits in patients with unilateral knee osteoarthritis, as compared with an age-matched group of healthy controls. They postulated that decreased activity associated with knee pain may lead to the decrease in proprioceptive abilities. Obviously, patients with shoulder instability limit their activity because of the increased risk of dislocation. Another explanation was attributed to the central loss of proprioception, which may induce knee degeneration, as occurs in Charcot joints. The existence of primary proprioception dysfunction could lead to a higher susceptibility to injuries and an increased risk of instability. Nontraumatic shoulder instability without tissue damage caused by abnormal neuromuscular control and muscle patterning has been widely described.[10,30] This pathology usually affects both shoulders. For such patients, a rehabilitation program without any surgical intervention is the main treatment and is mostly successful.[10,34] Authors have suggested integration of peripheral, visual, and vestibular input at all levels of central programming to restore neuromuscular control.[14,15,30]

Study limitations

One of the limitations of our study is that we cannot distinguish the real reason for bilateral instability. This is partly related to the methodology of proprioception assessment.[1,24,29] We used the active mode to reproduce the angle. Therefore, we assessed not only the sense itself but also the ability to actively control the arm. On the other hand, this type of evaluation seems to be more functional and corresponds with activities of daily living. Obviously, we could not also assess brain function or nerve conduction, which would be interesting to observe and may be the subject of further studies. Another interesting issue would be the behavior of JPS in the set of patients postoperatively, mostly to determine whether the bilateral deficits improve with shoulder recovery in both shoulders or 1 shoulder. They may possibly be persistent in all or some patients as is the case with persistent apprehension in some patients after shoulder stabilization. Another limitation is uneven matching of female and male participants between the groups: There was a higher proportion of female participants in the control group than in the instability group. We assumed that in our groups, this issue would not have affected the results because there was no difference in EARJP between the sexes in the control group and the results were pooled. No analysis was performed to investigate the influence of sex and arm dominance in the instability group. We assumed that it would not matter because there was no difference related to those factors in the control group. This issue is beyond the scope of our study. We did not specifically measure the physical activity of the study participants; however, none of the participants (in either the control or instability group) were professional athletes in any sport.

Conclusions

Active control of the shoulder is decreased by traumatic shoulder instability. However, significant proprioception deficits were found in both the affected and unaffected shoulders in patients with unilateral instability. Neither sex nor arm dominance influenced JPS and matching ability. Neuromuscular control improves as the arm is positioned in higher angles of elevation or rotation.

Disclaimer

This project was funded by the National Science Center based on decision number N403 01832/1319 and DEC-2011/01/B/NZ7/03596.

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ager AL, Roy JS, Roos M, Belley AF, Cools A, Hébert LJ. Shoulder proprioception: how is it measured and is it reliable? A systematic review. J Hand Ther 2017;30:221-31. http://dx.doi.org/10.1016/j.jht.2017.05.003
2. Alstermark B, Isa T, Pettersson LG, Sasaki S. The C3-C4 propriospinal system in the cat and monkey: a spinal pre-motoneuronal centre for voluntary motor control. Acta Physiol (Oxf) 2007;189:123-40. http://dx.doi.org/10.1111/j.1748-1716.2006.01655.x
3. Anderson VB, Wee E. Impaired joint proprioception at higher shoulder elevations in chronic rotator cuff pathology. Arch Phys Med Rehabil 2011;92:1146-51. http://dx.doi.org/10.1016/j.apmr.2011.02.004
4. Aydin T, Yildiz Y, Yanmis C, Kalyon T. Shoulder proprioception: a comparison between the shoulder joint in healthy and surgically repaired shoulders. Arch Orthop Trauma Surg 2001;121:422-5.
5. Badagliacco JA, Karduna A. College pitchers demonstrate directional differences in shoulder joint position sense compared to controls. J Sport Rehabil 2017;17:1-19. http://dx.doi.org/10.1123/jsr.2017-0007
6. Bank PJ, Peper CE, Marinus J, Beek PJ, van Hilten JJ. Motor consequences of experimentally induced limb pain: a systematic review. Eur J Pain 2013;17:145e57. http://dx.doi.org/10.1002/j.1532-2149.2012.00186.x
7. Barden JM, Balyk R, Raso VJ, Moreau M, Bagnall K. Dynamic upper limb proprioception in multidirectional shoulder instability. Clin Orthop Relat Res 2004;(420):181-9.
8. Blasier RB, Carpenter JE, Huston LJ. Shoulder proprioception: effect of joint laxity, joint position, and direction of motion. Orthop Rev 1994;23:45-50.
9. Brunt D, Andersen JC, Huntsman B, Reinhert LB, Thorell AL, Sterling JC. Postural responses to lateral perturbation in healthy subjects and ankle sprain patients. Med Sci Sports Exerc 1992;24:171-6.
10. Burkhead WZ Jr, Rockwood CA Jr. Treatment of instability of the shoulder with an exercise program. J Bone Joint Surg Am 1992;74:890-6.
11. Derscheid GL, Brown WC. Rehabilitation of the ankle. Clin Sports Med 1985;4:527-44.
12. Dilek B, Gulbahar S, Gundogdu M, Ergin B, Manisali M, Ozkan M, et al. Efficacy of proprioceptive exercises in patients with subacromial impingement syndrome: a single-blinded randomized controlled study. Am J Phys Med Rehabil 2016;95:169-82. http://dx.doi.org/10.1097/PHM.0000000000000327
13. Dos Santos GL, Salazar LF, Lazarin AC, de Russo TL. Joint position sense is bilaterally reduced for shoulder abduction and flexion in chronic hemiparetic individuals. Top Stroke Rehabil 2015;22:271-80. http://dx.doi.org/10.1179/1074935714Z.0000000014
14. Emery CA, Roy TO, Whittaker JL, Nettel-Aguirre A, van Mechelen W. Neuromuscular training injury prevention strategies in youth sport: a systematic review and meta-analysis. Br J Sports Med 2015;49:865-70. http://dx.doi.org/10.1136/bjsports-2015-094639
15. Etty Griffin LY. Neuromuscular training and injury prevention in sports. Clin Orthop Relat Res 2003;(409):53-60. http://dx.doi.org/10.1097/01.blo.0000057788.10364.aa
16. Fortier S, Basset FA. The effects of exercise on limb proprioceptive signals. J Electromyogr Kinesiol 2012;22:795-802. http://dx.doi.org/10.1016/j.jelekin.2012.04.001
17. Freeman MA, Wyke B. Articular contributions to limb muscle reflexes. The effects of partial neurectomy of the knee-joint on postural reflexes. Br J Surg 1966;53:61-8.
18. Fremerey R, Bosch U, Freitag N, Lobenhoffer P, Wippermann B. Proprioception and EMG pattern after capsulolabral reconstruction in shoulder instability: a clinical and experimental study. Knee Surg Sports Traumatol Arthrosc 2006;14:1315-20. http://dx.doi.org/10.1007/s00167-006-0084-z
19. Fyhr C, Gustavsson L, Wassinger C, Sole G. The effects of shoulder injury on kinaesthesia: a systematic review and meta-analysis. Man Ther 2015;20:28-37. http://dx.doi.org/10.1016/j.math.2014.08.006
20. Goble DJ. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. Phys Ther 2010;90:1176-84. http://dx.doi.org/10.2522/ptj.20090399
21. Goble DJ, Coxon JP, Van Impe A, Geurts M, Doumas M, Wenderoth N, et al. Brain activity during ankle proprioceptive stimulation predicts balance performance in young and older adults. J Neurosci 2011;31:16344-52. http://dx.doi.org/10.1523/JNEUROSCI.4159-11.2011
22. Haik MN, Camargo PR, Zanca GG, Alburquerque-Sendín F, Salvini TF, Mattiello-Rosa SM. Joint position sense is not altered during shoulder medial and lateral rotations in female assembly line workers with shoulder impingement syndrome. Physiother Theory Pract 2013;29:41-50. http://dx.doi.org/10.3109/09593985.2012.676722
23. Haller S, Cunningham G, Laedermann A, Hofmeister J, Van De Ville D, Lovblad KO, et al. Shoulder apprehension impacts large-scale functional brain networks. AJNR Am J Neuroradiol 2014;35:691-7. http://dx.doi.org/10.3174/ajnr.A3738
24. Han J, Waddington G, Adams R, Anson J, Liu Y. Assessing proprioception: a critical review of methods. J Sport Health Sci 2016;5:80-90.
25. Hasan Z, Stuart DG. Animal solutions to problems of movement control: the role of proprioceptors. Annu Rev Neurosci 1988;11:199-223.
26. Hodges P, van den Hoorn W, Dawson A, Cholewicki J. Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence. J Biomech 2009;42:61e6. http://dx.doi.org/10.1016/j.jbiomech.2008.10.001
27. Hung YJ, Darling WG. Shoulder position sense during passive matching and active positioning tasks in individuals with anterior shoulder instability. Phys Ther 2012;92:563-73. http://dx.doi.org/10.2522/ptj.20110236
28. Iida N, Kaneko F, Aoki N, Shibata E. The effect of fatigued internal rotator and external rotator muscles of the shoulder on the shoulder

position sense. J Electromyogr Kinesiol 2014;24:72-7. http://dx.doi.org/10.1016/j.jelekin.2013.10.008
29. Itoi E, Hsu H, An K. Biomechanical investigation of glenohumeral joint. J Shoulder Elbow Surg 1996;5:407-24.
30. Jaggi A, Lambert S. Rehabilitation for shoulder instability. Br J Sports Med 2010;44:333-40. http://dx.doi.org/10.1136/bjsm.2009.059311
31. Jankowska E. Interneuronal relay in spinal pathways from proprioceptors. Prog Neurobiol 1992;38:335-78.
32. Janwantanakul P, Magarey ME, Jones MA, Dansie BR. Variation in shoulder position sense at mid and extreme range of motion. Arch Phys Med Rehabil 2001;82:840-4.
33. Jerosch J, Thorwesten L, Steinbeck J, Reer R. Proprioceptive function of shoulder girdle in healthy volunteers. Knee Surg Sports Traumatol Arthrosc 1996;3:219-25.
34. Kim SH, Park JC, Park JS, Oh I. Painful jerk test: a predictor of success in nonoperative treatment of posteroinferior instability of the shoulder. Am J Sports Med 2004;32:1849-55.
35. Koralewicz LM, Engh GA. Comparison of proprioception in arthritic and age-matched normal knees. J Bone Joint Surg Am 2000;82:1582-8.
36. Lephart SM, Myers JB, Bradley JP, Fu FH. Shoulder proprioception and function following thermal capsulorraphy. Arthroscopy 2002;18:770-8.
37. Lephart SM, Warner J, Borsa P. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. J Shoulder Elbow Surg 1994;3:371-80.
38. Lin YL, Karduna A. Errors in shoulder joint position sense mainly come from the glenohumeral joint. J Appl Biomech 2017;33:32-8. http://dx.doi.org/10.1123/jab.2016-0034
39. Lubiatowski P, Ogrodowicz P, Wojtaszek M, Kaniewski R, Stefaniak J, Dudzinski W, et al. Measurement of active shoulder proprioception: dedicated system and device. Eur J Orthop Surg Traumatol 2013;23:177-83. http://dx.doi.org/10.1007/s00590-012-0950-y
40. Lubiatowski P, Olczak I, Lisiewicz E, Ogrodowicz P, Bręborowicz M, Romanowski L. Elbow joint position sense after total elbow arthroplasty. J Shoulder Elbow Surg 2014;23:693-700. http://dx.doi.org/10.1016/j.jse.2014.01.016
41. Machner A, Merk H, Becker R, Rohkohl K, Wissel H, Pap G. Kinesthetic sense of the shoulder in patients with impingement syndrome. Acta Orthop Scand 2003;1:85-8. http://dx.doi.org/10.1080/00016470310013716
42. Markey KL. Functional rehabilitation of the anterior cruciate ligament deficient knee. Sports Med 1991;12:407-17.
43. Myers JB, Lephart SM. The role of the sensorimotor system in the athletic shoulder. J Athl Train 2000;35:351-63.
44. Myers JB, Oyama S. Sensorimotor factors affecting outcome following shoulder injury. Clin Sports Med 2008;27:481-90. http://dx.doi.org/10.1016/j.csm.2008.03.005
45. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 1971;9:97-113.
46. Pettersson LG, Alstermark B, Blagovechtchenski E, Isa T, Sasaski S. Skilled digit movements in feline and primate-recovery after selective spinal cord lesions. Acta Physiol (Oxf) 2007;189:141-54. http://dx.doi.org/10.1111/j.1748-1716.2006.01650.x
47. Pollock R. Role of shoulder stabilization relative to restoration of neuromuscular control in joint kinematics. In: Lephart S, Fu F, editors. Proprioception and neuromuscular control in joint stability. 1st ed. Champaign, IL: Human Kinetics; 2000. p. 265-75.
48. Pötzl W, Thorwesten L, Götze C, Garmann S, Steinbeck J. Proprioception of the shoulder joint after surgical repair for instability: a long-term follow up study. Am J Sports Med 2004;32:425-30. http://dx.doi.org/10.1177/0363546503261719
49. Relph N, Herrington L. The effect of conservatively treated a ACL injury on knee joint position sense. Int J Sports Phys Ther 2016;11:536-43.
50. Roberts D, Fridén T, Stomberg A, Lindstrand A, Moritz U. Bilateral proprioceptive defects in patients with a unilateral anterior cruciate ligament reconstruction: a comparison between patients and healthy individuals. J Orthop Res 2000;18:565-71.
51. Roga M, Lubiatowski P, Lisiewicz E, Romanowski L. Analysis of normal glenohumeral joint proprioception. Issue Rehabil Orthop Neurophysiol Sport Promot 2013;5:15-30.
52. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. J Shoulder Elbow Surg 2001;10:438-44.
53. Sahin E, Dilek B, Baydar M, Gundogdu M, Ergin B, Manisali M, et al. Shoulder proprioception in patients with subacromial impingement syndrome. J Back Musculoskelet Rehabil 2017;30:857-62. http://dx.doi.org/10.3233/BMR-160550
54. Salles JI, Velasques B, Cossich V, Nicoliche E, Ribeiro P, Amaral MV, et al. Strength training and shoulder proprioception. J Athl Train 2015;50:277-80. http://dx.doi.org/10.4085/1062-6050-49.3.84
55. Shitara H, Shimoyama D, Sasaki T, Hamano N, Ichinose T, Yamamoto A, et al. The neural correlates of shoulder apprehension: a functional MRI study. PLoS One 2015;10:e0137387. http://dx.doi.org/10.1371/journal.pone.0137387
56. Smetacek V, Mechsner F. Making sense. Nature 2004;432:21. http://dx.doi.org/10.1038/432021a
57. Sole G, Osborne H, Wassinger C. The effect of experimentally-induced subacromial pain on proprioception. Man Ther 2015;20:166-70. http://dx.doi.org/10.1016/j.math.2014.08.009
58. Spargoli G. The acute effects of concentric versus eccentric muscle fatigue on shoulder active repositioning sense. Int J Sports Phys Ther 2017;12:219-26.
59. Sullivan JA, Hoffman MA, Harter RA. Shoulder joint position sense after thermal, open, and arthroscopic capsulorrhaphy for recurrent anterior instability. J Shoulder Elbow Surg 2008;17:389-94. http://dx.doi.org/10.1016/j.jse.2007.11.015
60. Suprak DN, Osternig LR, van Donkelaar P, Karduna AR. Shoulder joint position sense improves with elevation angle in a novel, unconstrained task. J Orthop Res 2006;24:559-68. http://dx.doi.org/10.1002/jor.20095
61. Takasaki H, Lim EC, Soon B. The effect of shoulder muscle fatigue on active repositioning acuity and scapulothoracic resting alignment: a systematic review with meta-analysis. Phys Ther Sport 2016;20:61-78. http://dx.doi.org/10.1016/j.ptsp.2016.01.001
62. Tibone JE, Fechter J, Kao JT. Evaluation of a proprioception pathway in patients with stable and unstable shoulders with somatosensory cortical evoked potentials. J Shoulder Elbow Surg 1997;6:440-3.
63. Tripp BL, Yochem EM, Uhl TL. Functional fatigue and upper extremity sensorimotor system acuity in baseball athletes. J Athl Train 2007;42:90-8.
64. Vafadar AK, Côté JN, Archambault PS. Sex differences in the shoulder joint position sense acuity: a cross-sectional study. BMC Musculoskelet Disord 2015;16:273. http://dx.doi.org/10.1186/s12891-015-0731-y
65. Wassinger CA, Myers JB, Gatti JM, Conley KM, Lephart SM. Proprioception and throwing accuracy in the dominant shoulder after cryotherapy. J Athl Train 2007;42:84-9.
66. Yasuda K, Sato Y, Iimura N, Iwata H. Allocation of attentional resources toward a secondary cognitive task leads to compromised ankle proprioceptive performance in healthy young adults. Rehabil Res Pract 2014;2014:7. http://dx.doi.org/10.1155/2014/170304
67. Zanchi D, Cunningham G, Lädermann A, Ozturk M, Hoffmeyer P, Haller S. Structural white matter and functional connectivity alterations in patients with shoulder apprehension. Sci Rep 2017;7:42327. http://dx.doi.org/10.1038/srep42327
68. 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;12:105-9. https://doi.org/10.1067/mse.2003.4