Arch Orthop Trauma Surg (2011) 131:1077–1084
DOI 10.1007/s00402-011-1285-6

ARTHROSCOPY AND SPORTS MEDICINE

The laser-pointer assisted angle reproduction test for evaluation of proprioceptive shoulder function in patients with instability

Maurice Balke · D. Liem · N. Dedy · L. Thorwesten · Maryam Balke · W. Poetzl · B. Marquardt

Received: 25 August 2010 / Published online: 25 February 2011

Abstract
Introduction Over the last decade, proprioceptive function gained increasing attention in joint disorders such as instability of the shoulder. Common tests for evaluation of proprioception are limited by their complexity and high technical demands. Thus, they are hardly applicable during daily routine. Our hypothesis was that the simplified "laser-pointer assisted angle reproduction test" (LP-ART) presented here allows for clinically feasible assessment of proprioceptive shoulder function.
Methods Active angle reproduction capability as an aspect of sensorimotor function was evaluated with the new method in patients with shoulder instability ($n = 24$) and healthy controls ($n = 24$). 15 patients had traumatic, 9 non-traumatic anterior instability (6 bilateral), 17 were treated surgically, 13 non-operatively. Tests were performed in flexion and abduction in different angles (55°, 90°, 125°) in randomized order.
Results Angle reproduction capability was worst below shoulder level (55°) in all groups. Best results were achieved at shoulder level (90°). Healthy controls showed overall better results than patients with instability. Patients after surgical stabilization had better results in 55° and 90° abduction compared to instability patients before surgery.
Conclusions The new LP-ART presented here is a technically simple, yet effective instrument for evaluation of the proprioceptive function of the shoulder. In contrast to former test setups it is feasible in daily routine. Compared to healthy controls, patients with unstable shoulder joints show significant proprioceptive disorders that can be quantified by the LP-ART.

Keywords Proprioception · Instability · Shoulder · Angle reproduction test · Joint position sense

Maurice Balke (✉)
Department of Trauma and Orthopedic Surgery,
University of Witten-Herdecke,
Cologne-Merheim Medical Center,
Ostmerheimer Str. 200, Cologne 51109, Germany
e-mail: maurice.balke@gmail.com

D. Liem · N. Dedy
Department of Orthopaedic Surgery,
University Hospital Muenster,
Albert-Schweitzer-Str. 33, Muenster 48149, Germany

L. Thorwesten
Department of Sports Medicine,
University Hospital of Muenster, Muenster, Germany

Maryam Balke
Department of Neurology, Knappschaftskrankenhaus,
Ruhr-University of Bochum, In der Schornau 23-25,
Bochum 44892, Germany

W. Poetzl
Department of Shoulder and Elbow Surgery,
Vulpiusklinik, Bad Rappenau, Germany

B. Marquardt
Orthopedic Practice Clinic, Muenster, Germany

Introduction

In the beginning of the last century, Perthes postulated the importance of the joint capsule and glenohumeral ligaments for the stability of the shoulder joint [23]. More than 80 years ago, Bankart first described the typical labral tear as the main cause for posttraumatic anterior shoulder instability, referred to as "Bankart-lesion" [5]. As a result he developed the surgical refixation-procedure of the labrum which is used until today.

During the last decade, the sensorimotor function gained growing attention in joint stability disorders [10, 32]. Especially in the shoulder joint, where stability is mainly provided by muscles and tendons, proprioceptive function seems to be of high importance [16, 31].

Proprioception is defined as the sense of position and movement of the body and extremities. The joint position sense (JPS) provides the organism with information about speed and direction of active and passive movements without visual control. Specific receptors (proprioceptors, mechanoceptors) located in the skin, muscles and tendons detect the proprioceptive information and send it to the central nervous system. The sense of positioning is transmitted through the muscle spindle receptors measuring lengthening of the muscles and through the Golgi tendon organ measuring muscle tension. Proximal joints (e.g. shoulder) have a lower sensory threshold than distal joints (e.g. fingers). Injury to tissues containing the respective receptors can cause proprioceptive deficits [17].

Despite their clinical importance studies in this field are rare. This might be explained by the complexity and poor practicability of existing tests [14]. Jerosch and Potzl have used a motion-analyzing system with passive reflecting markers and a CCD-camera connected to a computer system for documentation of joint positioning [16, 24]. Although this setup is validated for standardized measurements of proprioceptive function, it is hardly feasible during clinical routine.

More extensive research on proprioceptive function of the shoulder joint would lead to improvements in surgical as well as conservative treatments. Therefore, reproducible and easy to use test setups are an important precondition.

In our study, we have evaluated a new method for active angle reproduction measurement which we called "the laser-point assisted angle reproduction test" (LP-ART). Our hypothesis was that the simplified test setup presented here allows for clinically feasible assessment of proprioceptive shoulder function.

Patients and methods

A total of 48 subjects in two different groups were tested with the LP-ART. One group included 24 patients with shoulder instability (7 female, 17 male; mean age 24.7 ± 5.3), of whom 6 had affections of both shoulders. Thus, 30 instable shoulders were included in the study, of which 17 had been treated operatively and 13 without operation (Table 1). This group was compared to 24 healthy controls (13 female, 11 male; mean age 24.7 ± 1.1).

All participants of the study were asked to fill out a questionnaire that comprised age, gender, height and weight, general condition, physical practice, history of trauma and respective treatment, subjective evaluation of shoulder complaints like pain, reduction in range of motion, and instability (0 = no complaints, 4 = maximal complaints). Test persons were also asked to specify their activities immediately prior to test including physical activity, alcohol consumption, and sleep.

Table 1 Overview of patient collective

#	Gender	Age	Trauma	Side	Surgery
1	F	25	Y	R	N
2	M	25	Y	R	Y
3	M	31	Y	L	Y
4	M	27	Y	R	Y
5	M	31	Y	L	Y
6	F	24	Y	L	Y
7	M	27	Y	L	N
8	M	26	Y	L	Y
9	F	37	N	R/L	N/N
10	M	31	N	R/L	Y/Y
11	M	21	Y	R	N
12	M	19	Y	R	N
13	M	25	N	R/L	Y/N
14	M	18	Y	L	Y
15	M	17	Y	L	Y
16	M	30	Y	L	Y
17	F	26	N	R/L	N/Y
18	M	18	N	L	Y
19	M	18	N	L	N
20	F	17	N	R/L	N/Y
21	M	28	Y	R	Y
22	M	21	Y	R	N
23	F	25	N	L	N
24	F	26	N	R/L	N/Y

F female, *M* male, *Y* yes, *N* no, *R* right, *L* left

Inclusion criteria were traumatic ($n = 15$) or non-traumatic ($n = 9$; 6 bilateral) anterior shoulder instabilities; full and painless motion of both shoulder joints; below 40 years of age; free from acute shoulder symptoms. The control group consisted of healthy students below 40 years of age which were free from chronic or acute shoulder disorders and had no history of shoulder trauma.

The laser-pointer assisted angle reproduction test (LP-ART)

To prevent external stimulation of mechanoreceptors located in the skin [11] all subjects were examined with bare chest (females wearing bikini). The test person was standing at a marked line on the floor that was drawn parallelly and in one meter distance to a target board fixed on the opposite wall (Fig. 1a). The target board was

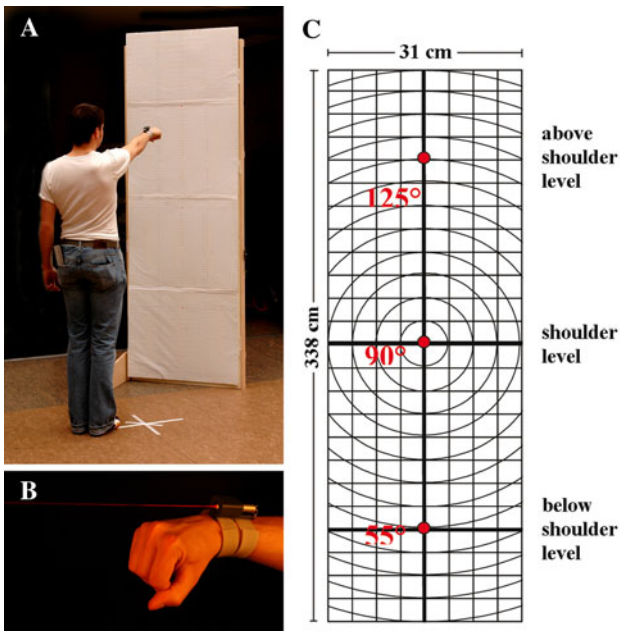

Fig. 1 LP-ART test setup. **a** patient positioning, **b** laser pointer affixed to the dorsal aspect of the subject's wrist. **c** Target board with standardized coordinate system indicating the different angles of motion

adjustable in height so that point zero could be aligned individually with the glenohumeral joint of every patient. A standardized coordinate system drawn on the target board indicated the different angles of motion (Fig. 1c), which were calculated using the formula: $r = 100\ \text{cm} \times \tan \alpha$. A laser-pointer was affixed to the dorsal aspect of the patient's wrist with a Velcro strap (Fig. 1b). The test person was asked to raise their affected arm from hanging (neutral) position to aim for assigned points at 55°, 90° and 125°. The 90° position was defined as point zero. The patient was required to memorize the different joint positions. In the next step, the patient's eyes were covered to inhibit visual control. Then they were asked to reproduce the same joint positions as before in a randomized order. The coordinates of the position where the laser-pointer finally came to rest were marked and documented by an independent observer, without informing the patient.

This procedure was repeated 3 times for flexion and abduction respectively, so that 36 points were recorded for each subject. The evaluation of one patient took approximately 15 min. The deviations from the given angles (55°, 90°, 125°) were measured on the x- and y-axis. Absolute angle-deviations [c] were calculated with Microsoft Excel 2000 using the pythagorean proposition: $c = \sqrt{x^2 + y^2}$. The means of angle-deviation of both shoulders (dominant and non-dominant) of the controls were compared to the instable as well as the stable shoulder joints of the patients.

Statistical methods

Statistical analysis was performed using Microsoft Excel 2000 and SPSS Version 15.0. The normal distribution was proven by the Kolmogorov–Smirnov test, comparison of means was done by paired and unpaired t-tests. Level of significance was set at $P < 0.05$.

Results

General data

Five controls performed overhead sports regularly (3.6 h per week) and 14 preferred endurance training. In the patient group, 11 performed overhead sports regularly (3.2 h per week) and 3 preferred endurance sports. 19 patients reported no or minimal pain, 2 patients reported moderate pain and 3 patients reported strong or maximum pain. Control subjects did not have any pain while using their arm. 10 patients did refer no or minimal deficits in range of motion, 8 referred about moderate and 6 about strong or maximum deficits. Subjective feeling of instability was absent or minimal in 10 patients, moderate in 2 and strong or maximum in 12 patients. The range of motion necessary for the different tests was achieved without pain in all subjects.

Controls

There were no significant differences between the dominant and non-dominant shoulder in the control group so that in further analyses the mean values of both shoulders were combined. Significant differences in angle reproduction capability (ARC) were found in the following measurements (Fig. 2): 125° versus 90° flexion ($P = 0.012$); 90° versus 55° flexion ($P = 0.003$); 90° versus 55° abduction ($P = 0.004$). In flexion as well as abduction the best ARC was achieved at shoulder level (90°) and the worst below shoulder level (55°). No significant differences were found between men and women.

Patients

Unstable versus stable (contralateral) shoulders

To compare unstable to stable contralateral shoulders the six patients with bilateral instability were excluded. Thus, 18 stable shoulders were compared to 24 unstable shoulders (Fig. 2). In 55° flexion, best results in ARC were achieved with the unstable shoulder, whereas in 90° and 125° the stable shoulders achieved better results (Fig. 2a).

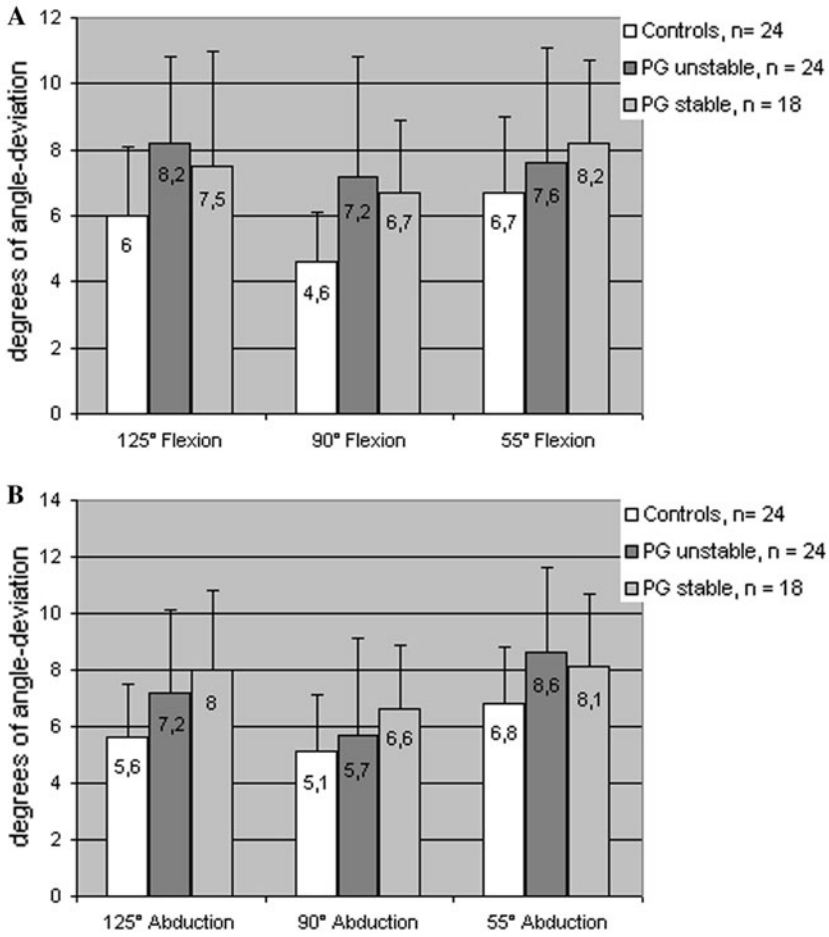

Fig. 2 Controls versus unstable and stable patient shoulders. Diagram showing the results of the angle reproduction test in flexion (**a**) and abduction (**b**). The numbers within the columns show the mean degrees of angle-deviation. *PG* patient group

For abduction, best accuracy was achieved with the unstable shoulder at 90°, whereas worst results were achieved at 55° (Fig. 2b). None of the differences were significant.

When comparing the ARC of abduction in unstable shoulders, best results were achieved at 90° and worst results at 55°. The differences were statistically significant ($P = 0.009$). For the stable shoulders significant differences were found when comparing 90°–55° abduction ($P = 0.038$). With the unstable shoulder men ($n = 17$) presented significantly better results than women ($n = 7$) in 125° flexion ($P = 0.006$). At all other angles as well as for the stable shoulder there were no significant differences.

Traumatic versus non-traumatic instabilities

Concerning flexion, the non-traumatic unstable shoulders were slightly better at 90° and 55°, whereas at 125° the traumatic shoulders were significantly better ($P = 0.011$). Regarding abduction, the traumatic unstable shoulders were slightly better at all angles without reaching statistical significance (Fig. 3).

Operated versus non-operated shoulders

The accuracy in ARC was better for operated ($n = 13$) compared to non-operated ($n = 17$) unstable shoulders at all levels except for 55° flexion, but none of the differences were significant (Fig. 4).

Controls versus patients

Angle-deviations of the controls ($n = 24$) were either compared to unstable ($n = 24$) or to stable ($n = 18$) patient shoulders (Fig. 2). For flexion as well as abduction best results were achieved by the control group at all angles. When comparing control shoulders to unstable patient shoulders, significant differences were found for 90° flexion ($P = 0.002$) and 125° flexion ($P = 0.002$), 125° abduction ($P = 0.035$) and 55° abduction ($P = 0.02$). When comparing control shoulders to stable patient shoulders significant differences were found for 90° flexion ($P = 0.001$), 125° abduction ($P = 0.002$) and 90° abduction ($P = 0.03$). In flexion, controls tended to deviate medially (left with right arm and vice versa) with according findings in the patient group.

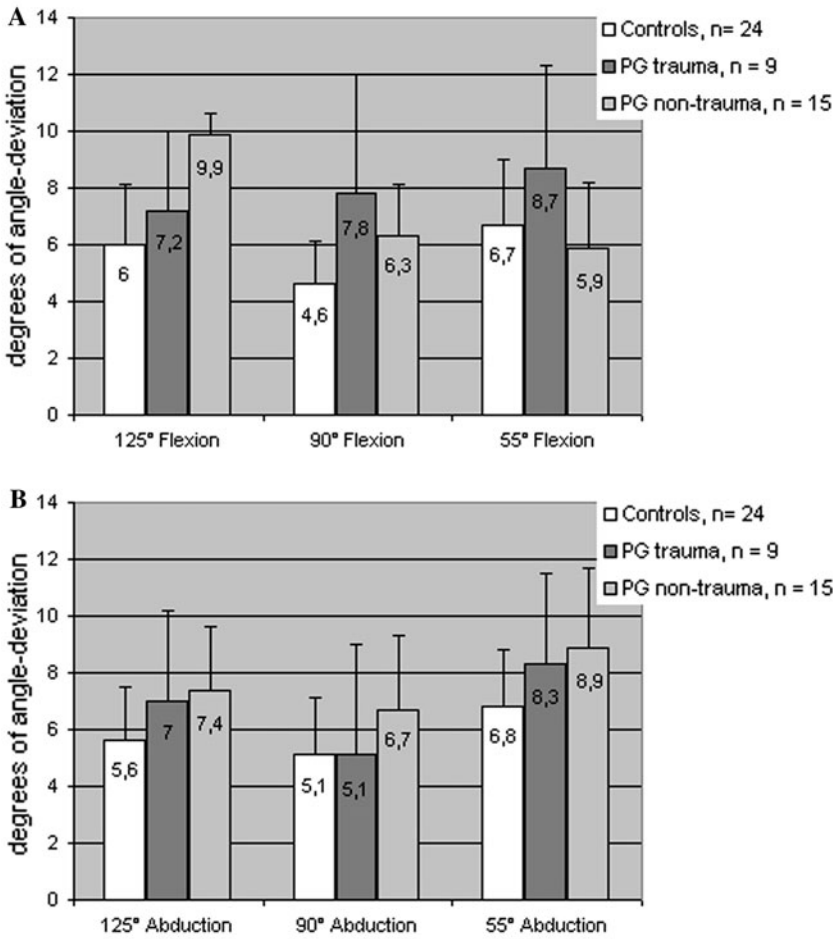

Fig. 3 Controls versus traumatic and non-traumatic instabilities. Diagram showing the results of the angle reproduction test in flexion (**a**) and abduction (**b**). The numbers within the columns show the mean degrees of angle-deviation. *PG* patient group

Discussion

The aim of this study was to evaluate if the simplified angle reproduction test presented here allows for clinically feasible assessment of proprioceptive shoulder function. Several studies have addressed the methodological problems in passive and active angle reproduction tests [16, 24]. There is still no standardization for test setup, reproduction angles, number of necessary tests and calculation of angle-deviations. All these parameters can potentially be of methodological value. Sensorimotor (proprioceptive) function also correlates with the ability of accurate joint positioning [20] but it is hardly possible to compare the results of single studies with one another. The current active and passive angle reproduction tests are suitable for studies but not for diagnostic use.

One specific problem in our test setup occurred with the fixation of the laser pointer to the wrist (Fig. 1b). Some subjects tended to dorsiflex the wrist which interrupted the laser beam. In these cases, the test had to be repeated. For future studies, we recommend the use of an additional brace to prevent from accidental wrist movements. A possible weakness of our experimental design could be the fixation of the laser pointer to the wrist with a Velcro strap, which might have activated the mechanoreceptors. But it is very unlikely that this activation significantly influenced the upper extremity position sense.

Since external influences such as alcohol [3, 22], lack of sleep [28], muscle fatigue [7, 30] or athletic activities [1, 27] may affect proprioceptive function we evaluated these sources of error by means of a questionnaire. None of these factors correlated with deviant or unexpected results in our collection. We had expected the preference in overhead sports in the patient group since overhead athletes more often suffer from shoulder instability [2, 8]. In the literature, the influence of overhead sports on shoulder proprioception is discussed controversially. Some authors report deficits in angle reproduction capability [1, 27], whereas others published contrary results [15]. There was no significant difference in our collective.

The control group achieved slightly better results in angle reproduction with the dominant shoulder compared to the non-dominant one, a phenomenon already described by Aydin et al. [4]. This may be because proprioception is

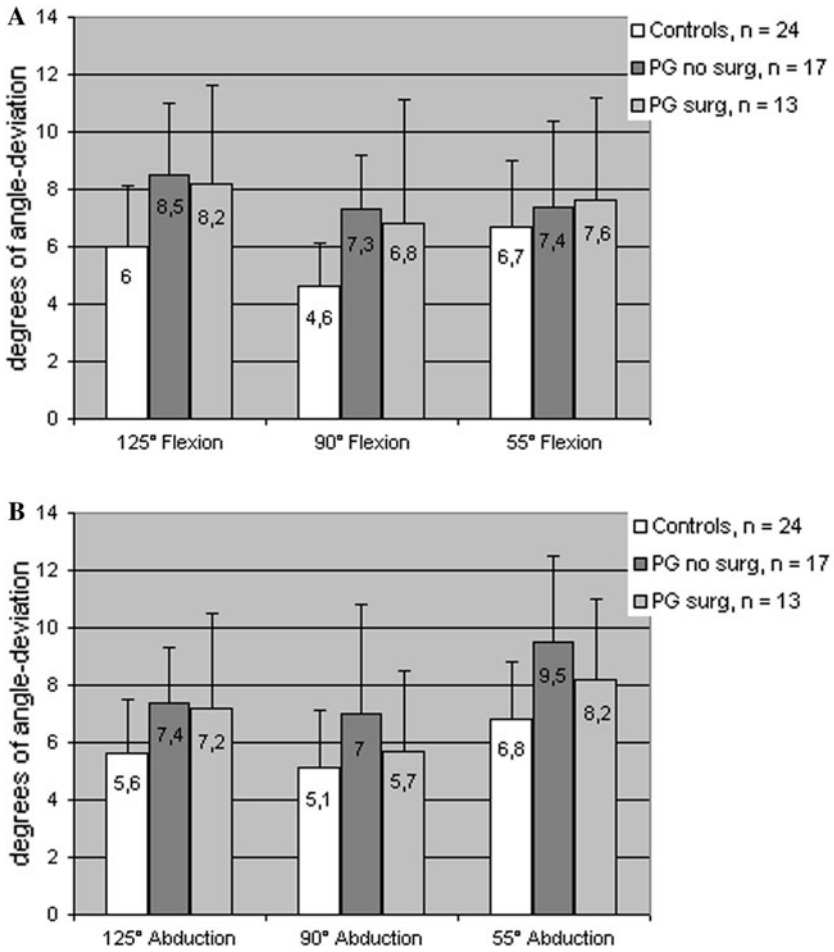

Fig. 4 Controls versus non-surgically and surgically treated instabilities. Diagram showing the results of the angle reproduction test in flexion (**a**) and abduction (**b**). The numbers within the columns show the mean degrees of angle-deviation. *PG* patient group

influenced by learning processes [25]. Most movements are performed by the dominant arm, theoretically leading to better proprioceptive abilities [25]. We tried to minimize learning processes as far as possible; patients were not given any feedback on their test results, their eyes were covered and the different joint angles were tested in randomized order.

Test results controls

Interestingly, controls tended to deviate medially in flexion tests, which is most likely caused by additional internal rotation. Several studies have shown that proprioceptive capability is more precise in external rotation [7]. This is probably caused by an increased tension of the joint capsule, leading to increased activity of the mechanoreceptors, again leading to more precise sensorimotor function [4, 6].

Former publications did not report on gender specific differences in ARC [16] which is in accordance with our findings. The significantly worse results in the female group at 125° are most likely accidental because this group consisted of only 7 women.

Other authors have already published that best results were generally achieved at shoulder level, whereas worst results were achieved below shoulder level [16]. This is in accordance with our findings and might be explained by the lack of tension of the joint capsule at 55° [16, 18] leading to reduced activation of the mechanoreceptors [21]. There are several reports that proprioceptive capabilities increase with increasing range of motion and respective tensioning of the capsular structures [4, 13, 15, 19]. At shoulder level (90°) the tension is balanced [13, 19]. Interestingly, the results at 125° were worse than at 90° although the tension of the capsule should be higher. This could be explained by the biomechanical properties of the shoulder joint. Movements above shoulder level are no longer performed exclusively in the glenohumeral joint, but involve the scapulothoracic joint as well. It can be assumed that the more anatomical structures are involved, the less precise proprioceptive functions become. Another explanation might be the fact that most activities of daily living are performed below or at shoulder level and rarely overhead [13]. Considering that learning processes influence proprioception [25] the JPS may be best when performing every-day movements.

Test results patients

No significant differences in ARC were found comparing stable to unstable patient shoulders. This is in contrast to the literature where significant deficits are reported for the latter [1, 4]. This discrepancy is most likely because in our study, patients with non-traumatic shoulder instability were included: this collective presumably also has proprioceptive deficits of the contralateral, yet asymptomatic shoulder. The former studies cited here included post-traumatic instabilities only. Patients of such a collective have usually healthy contralateral shoulders. The shoulder joints of patients with post-traumatic instabilities probably did not have any proprioceptive deficits until that particular incidence, whereas shoulder joints of patients with non-traumatic instabilities usually present an increased laxity [26]. However, the validity of these results is limited by the small subgroups in our collective.

Surgical procedures aim either to reconstruct ruptured tendons or to tighten capsular structures. Both operations lead to increased tension and therefore improved activation of mechanoreceptors, which might positively influence the proprioceptive function [4, 9, 32]. Still, the regenerative potential of mechanoreceptors is discussed controversially [12, 29].

Controls versus patients

The control group achieved better overall results in ARC compared to the patient group with unstable shoulders. Other studies have documented that patients with chronic shoulder instability have deficits in proprioceptive function [32], which is explained by the general increased laxity of patients with shoulder instabilities. The recurrent dislocations and subsequent overexpansion of joint structures may even worsen the proprioceptive deficits [27]. Traumatic injuries of the capsule and tendons also lead to worsened proprioceptive functions. Traumatic destruction of afferent mechanoreceptors affect the information transfer to the central nervous system [20, 21].

Conclusion

The new laser-pointer assisted angle reproduction test (LP-ART) presented here is a technically simple, yet effective instrument for evaluation of the proprioceptive function of the shoulder joint. Compared to former test setups it is feasible in daily routine.

Compared to healthy controls, patients with unstable shoulder joints show significant proprioceptive disorders that can be quantified by the LP-ART.

Conflict of interest All authors declare no conflict of interest.

References

1. Allegrucci M, Whitney SL, Lephart SM, Irrgang JJ, Fu FH (1995) Shoulder kinesthesia in healthy unilateral athletes participating in upper extremity sports. J Orthop Sports Phys Ther 21:220–226
2. Altchek DW, Hobbs WR (2001) Evaluation and management of shoulder instability in the elite overhead thrower. Orthop Clin North Am 32:423–430 viii
3. Ando S, Iwata T, Ishikawa H, Dakeishi M, Murata K (2008) Effects of acute alcohol ingestion on neuromotor functions. Neurotoxicology 29:735–739
4. Aydin T, Yildiz Y, Yanmis I, Yildiz C, Kalyon TA (2001) Shoulder proprioception: a comparison between the shoulder joint in healthy and surgically repaired shoulders. Arch Orthop Trauma Surg 121:422–425
5. Bankart AS, Cantab MC (1993) Recurrent or habitual dislocation of the shoulder-joint. 1923. Clin Orthop Relat Res 3–6
6. Blasier RB, Carpenter JE, Huston LJ (1994) Shoulder proprioception. Effect of joint laxity, joint position, and direction of motion. Orthop Rev 23:45–50
7. Carpenter JE, Blasier RB, Pellizzon GG (1998) The effects of muscle fatigue on shoulder joint position sense. Am J Sports Med 26:262–265
8. Chan KM, Maffulli N, Nobuhara M, Wu JJ (1996) Shoulder instability in athletes. The Asian perspective. Clin Orthop Relat Res 106–112
9. Edmonds G, Kirkley A, Birmingham TB, Fowler PJ (2003) The effect of early arthroscopic stabilization compared to nonsurgical treatment on proprioception after primary traumatic anterior dislocation of the shoulder. Knee Surg Sports Traumatol Arthrosc 11:116–121
10. Good L, Roos H, Gottlieb DJ, Renstrom PA, Beynnon BD (1999) Joint position sense is not changed after acute disruption of the anterior cruciate ligament. Acta Orthop Scand 70:194–198
11. Herrington L, Simmonds C, Hatcher J (2005) The effect of a neoprene sleeve on knee joint position sense. Res Sports Med 13:37–46
12. Hogervorst T, Brand RA (1998) Mechanoreceptors in joint function. J Bone Joint Surg Am 80:1365–1378
13. Janwantanakul P, Magarey ME, Jones MA, Dansie BR (2001) Variation in shoulder position sense at mid and extreme range of motion. Arch Phys Med Rehabil 82:840–844
14. Jerosch J, Brinkmann T, Schneppenheim M (2003) The angle velocity reproduction test (AVRT) as sensorimotor function of the glenohumeral complex. Arch Orthop Trauma Surg 123:151–157
15. Jerosch J, Prymka M (1996) Proprioception and joint stability. Knee Surg Sports Traumatol Arthrosc 4:171–179
16. Jerosch J, Thorwesten L, Steinbeck J, Reer R (1996) Proprioceptive function of the shoulder girdle in healthy volunteers. Knee Surg Sports Traumatol Arthrosc 3:219–225
17. Lephart SM, Pincivero DM, Giraldo JL, Fu FH (1997) The role of proprioception in the management and rehabilitation of athletic injuries. Am J Sports Med 25:130–137
18. Levine WN, Flatow EL (2000) The pathophysiology of shoulder instability. Am J Sports Med 28:910–917
19. Lonn J, Crenshaw AG, Djupsjobacka M, Pedersen J, Johansson H (2000) Position sense testing: influence of starting position and type of displacement. Arch Phys Med Rehabil 81:592–597
20. Myers JB, Ju YY, Hwang JH, McMahon PJ, Rodosky MW, Lephart SM (2004) Reflexive muscle activation alterations in shoulders with anterior glenohumeral instability. Am J Sports Med 32:1013–1021
21. Myers JB, Lephart SM (2002) Sensorimotor deficits contributing to glenohumeral instability. Clin Orthop Relat Res 98–104

22. Noda M, Demura S, Yamaji S, Kitabayashi T (2004) Influence of alcohol intake on the parameters evaluating the body center of foot pressure in a static upright posture. Percept Mot Skills 98:873–887
23. Perthes G (1906) Über Operationen bei habitueller Schulterluxation. Dtsch Ztschr Chir 85:199–222
24. Potzl W, Thorwesten L, Gotze C, Garmann S, Steinbeck J (2004) Proprioception of the shoulder joint after surgical repair for Instability: a long-term follow-up study. Am J Sports Med 32:425–430
25. Redding GM, Wallace B (1990) Effects on prism adaptation of duration and timing of visual feedback during pointing. J Mot Behav 22:209–224
26. Rodeo SA, Suzuki K, Yamauchi M, Bhargava M, Warren RF (1998) Analysis of collagen and elastic fibers in shoulder capsule in patients with shoulder instability. Am J Sports Med 26:634–643
27. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ (2001) Shoulder proprioception in baseball pitchers. J Shoulder Elbow Surg 10:438–444
28. Skinner HB, Wyatt MP, Hodgdon JA, Conard DW, Barrack RL (1986) Effect of fatigue on joint position sense of the knee. J Orthop Res 4:112–118
29. Turkof E, Jurecka W, Sikos G, Piza-Katzer H (1993) Sensory recovery in myocutaneous, noninnervated free flaps: a morphologic, immunohistochemical, and electron microscopic study. Plast Reconstr Surg 92:238–247
30. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC (1996) The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. J Orthop Sports Phys Ther 23:348–352
31. Warner JJ, Lephart S, Fu FH (1996) Role of proprioception in pathoetiology of shoulder instability. Clin Orthop Relat Res 35–39
32. Zuckerman JD, Gallagher MA, Cuomo F, Rokito A (2003) The effect of instability and subsequent anterior shoulder repair on proprioceptive ability. J Shoulder Elbow Surg 12:105–109