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Arthroscopic chronic tennis elbow surgery preserves elbow proprioception

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ABSTRACT

Study design: Retrospective cohort study.
Introduction: A new method of accurately assessing the compromised elbow's proprioception was developed for this postsurgical population using information from previous neurophysiologic proprioception studies of healthy elbows.
Hypothesis: This retrospective cohort study investigated the patterns and the degree of proprioceptive impairment and recovery following arthroscopic surgery for chronic lateral epicondylitis.
Material and methods: Participants had undergone arthroscopic elbow surgery two years prior to this study ($n = 15$). Healthy, non-injured volunteers with similar demographics ($n = 15$) served as controls. Both groups were evaluated using quantitative measures of joint position sense for proprioceptive functioning. In order to obtain the most accurate proprioceptive measurements, interindividual interaction and visual input biases were eliminated. Retrospective chart reviews were performed to compare qualitative self-reported measures of proprioceptive function in arthroscopic surgery patients before surgery and two years post-surgery.
Results: Active and passive joint repositioning outcome measurements were similar between groups ($p > 0.05$). No significant differences were found among any angles except one: passive joint position sense at 120° of flexion ($p < 0.05$). At this angle, the arthroscopy group showed greater deviation from target angles than the control group. The novel proprioceptive testing method we developed was found to be accurate and reliable.
Discussion: Outcomes of arthroscopic treatment of chronic lateral epicondylitis with no decortication yielded outcomes measure similar to those of healthy controls. The sole significant difference was at 120° flexion passive joint repositioning, with a higher negative angular deviation from the target point. We propose that our study results and specific proprioception method may have implications for improving accuracy of future elbow arthroscopy and proprioceptive recovery in this population.
Level of evidence: II, low-powered prospective randomized trial.

1. Introduction

Lateral epicondylitis (tennis elbow) is the most frequent elbow disorder in adults [1,2]. This painful condition is usually felt 1 cm below the lateral epicondyle and often causes radiating pain into the forearm with active or resisted wrist extension [2,3]. One of the consequences of this condition is impairment of elbow proprioception [4]. Proprioception has been defined as 'the perception of movement and position of body segments in relation to each other without the aid of vision' [4]. Mechanoreceptors located in the joint, capsules, ligaments, muscles, tendons, and skin. Intact joint position sense is necessary for normal muscle coordination and timing [5]. Proprioception is generally divided into four domains, kinesthesia (joint position sense or replication, and movement sense), sense of tension, sense of effort and the sense of balance [6]. There is evidence that proprioception educational programs

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and proprioceptive rehabilitation improve primary healing, and reduce the incidence of re-injury thus, significant attention must be given to recovering proprioception loss [4,7].

Lateral epicondylitis is mostly self-limiting, taking 8–12 months to recover [2]. The prolonged recovery period is of particular concern to professional athletes and individuals who perform elbow-intensive activities regularly, as the injury can significantly disrupt their careers during prime competitive years. Conservative treatment consists of imposing modifications to general activities and taking breaks from sports activities [8]. Among lateral epicondylitis patients, 4% to 8% do not respond to conservative treatment [9–11].

Due to the extensive recovery period associated with conservative treatments, sports medicine specialists often find patients opting for surgery after conservative methods have failed in order to avoid career interruption. Approximately 10% of patients experience a moderate to poor outcome with surgical treatment, however Wada et al. reported positive outcomes in all 20 of the patients in their study who had received arthroscopic release surgery for chronic lateral epicondylitis [7,11,12]. While arthroscopic surgery was predominantly successful in the study by Grewal et al., they noted that patients involved in highly physical occupations experienced less favorable outcomes after surgery [13]. Peart et al. have reported better functional outcomes with minimally invasive arthroscopic treatment compared to open surgery [14]. Only a few studies reported that in the case of arthroscopic treatments, the injured were found to recover quicker and return to their regular activities sooner than patients who did not undergo treatment [15].

Despite the frequency of elbow injuries and the importance of retraining proprioception during recovery, little research has been conducted on the proprioceptive outcomes of various surgical treatments for these injuries compared to the comprehensive research that exists for shoulder and knee joint injuries. Proprioception is a precise and complicated parameter that is subject to confounding by patient visual perception when applied to the upper extremities. Such confounding has the potential to lead to unreliable study conclusions that could potentially lead to disease mismanagement.

A few studies have used limited proprioceptive methodology on the elbow joint and related injuries. A study by Juul-Kristensen et al. used an electrogoniometer and a motorized passive motion device to test elbow proprioception, and found that people with lateral epicondylitis had poorer proprioception compared to those with healthy elbows [4]. Another study by this group of researchers investigated proprioception measurement techniques in healthy elbows and found threshold to detection of passive motion (TDPM) to be a reliable measure for absolute error where as joint position sense lacked reliability [16].

A literature review by Goble and Brown elucidated recent studies supporting the complementary roles played by left and right arms, with each arm relying differently on proprioception versus visual input during bimanual activities [17]. They went on to investigate factors affecting elbow proprioceptive functioning from a neurophysiological perspective [18]. Their study looked into the role of visual and proprioceptive sensory inputs during proprioceptive tasks involving healthy, right upper limb-dominant elbows versus non-dominant limbs. They concluded that visual feedback was more important to controlling motor tasks in the dominant right upper extremity whereas non-dominant left arm movements were controlled by proprioceptive feedback [18]. Other studies by Goble et al. looked at the influence of factors such as static versus dynamic matching tasks, task difficulty and altered target presentation time in dominant versus non-dominant proprioceptive tasks [19,20]. Goble et al. have been involved in many of the elbow proprioception studies, however their studies involved healthy elbows [18–20]. The study by Juul-Kristensen et al. looked at proprioceptive deficits in those with lateral epicondylitis who had not been treated surgically [4].

In the present retrospective study, we evaluate proprioceptive outcomes of arthroscopic extensor carpi radialis brevis (ECRB) tendon release without decortication for chronic lateral epicondylitis. Proprioceptive parameters provide the most dependable means of accurately evaluating postoperative outcomes and reliably quantifying postoperative recovery and functioning. However, these parameters are subject to confounding by patient visual perception when applied to the upper extremities [17–20]. Such confounding could potentially result in unreliable conclusions that can lead to disease mismanagement. To eliminate visual perception and inter-participant interference biases, we developed and utilized a unique proprioceptive testing method that minimized these confounding factors using blindfolds and separate entrance doors for participants.

The aim of the study was to investigate the patterns and the degree of proprioceptive impairment and recovery following arthroscopic surgery for chronic lateral epicondylitis.

2. Material and methods

Our sample for retrospective analysis and prospective data collection consisted of 15 patients who were right dominant only, and who had undergone arthroscopic ECRB release without decortication procedure for chronic lateral epicondylitis at the orthopaedics and traumatology department of our institution from 2011 to 2013. Fifteen healthy, non-injured volunteers with equivalent demographics were recruited as the control group. Proprioceptive data measurements were performed on the dominant right arms of arthroscopy patients at a two-year postoperative follow up. The same protocol was applied to the controls. Patients and controls shared an activity profile that demanded high levels of upper limb activity, and included manual laborers as well as tennis, volleyball and basketball players. Proprioceptive testing was performed at our institution's sports medicine department from 2015–2016. Approval for the study was granted by the Ethics Committee of Suleyman Demirel University.

2.1. Participants

Patient inclusion criteria were:

- being 18–55 years of age;
- having a BMI of 18.5–24.9;
- being right upper limb dominant; participating in a high-demand upper limb activity;
- having a chronically painful (at least one-year history) of lateral epicondylitis that was unresponsive to at least two conservative treatment sessions (physical therapy, taping and extracorporeal shock wave therapy) plus at least two local anesthetic-steroid or PRP injections;
- having an MRI scan at our institution confirming the chronic lateral epicondylitis diagnosis; postoperatively having been treated with the same medication, physical therapy and rehabilitation protocol according to national standard guidelines by experienced specialists in anesthesiology, infectious diseases and physical therapy;
- being a native speaker of the investigational (national) language; being at least a high school graduate; and having a minimum of 2 years of consistent follow-ups.

Control group inclusion criteria were the same without the clinical history requirements: being 18–55 years of age; having an equivalent BMI of 18.5–24.9; being right upper limb dominant;

participating in a high-demand upper limb activity; and being a native speaker of the investigational (national) language and at least a high school graduate. A control group, instead of evaluating the contralateral side of the patients, was created in order to eliminate the individual proprioceptive testing experience bias and visual/sensational right/left cerebral hemispheral difference biases.

Exclusion criteria included;

- having ulnar, carpal and radial nerve entrapment syndromes;
- osteoarthritis, rheumatoid arthritis, diabetes and metabolic joint diseases;
- cervical pathologies;
- spondyloarthropathy; rotator cuff pathology; neurologic and psychiatric diseases;
- smoking; having a history of previous ipsilateral arm pain or trauma;
- ipsilateral fracture history; and having an inconsistent postoperative follow-up compliance.

2.2. Operative technique

Elbow arthroscopy was started with standard anteromedial and anterolateral portals and the diagnosis was confirmed arthroscopically. According to Baker classification all patients had type-II lesions (linear capsular tear). Single deep capsular fissures were detected in all patients.

The investigated surgical technique was arthroscopic extensor carpi radialis brevis (ECRB) release with no decortication via anteromedial and anterolateral elbow portals, under general anesthesia, with pneumatic tourniquet inflated to a pressure level no higher than 100 mmHg above the intraoperative systolic blood pressure of the patients. Common extensor tendon is not cut. Cefazolin-sodium (1000 mg intravenous) was administered 30 minutes prior to surgery. All the surgical procedures were performed by a single senior surgeon with extensive experience in elbow arthroscopy. An elbow specific outcome measure, Preoperative Mayo Elbow Performance Scores (MEPS), was obtained from patients before the arthroscopic procedure.

2.3. Postoperative period and rehabilitation

Postoperative patients were prescribed a standard pain management and antibiotic prophylaxis protocol in consultation with the anesthesiology and infectious disease specialists, who were blind to the study. Patients were discharged on the first postoperative day. Standard care included ten-day postoperative requirements of elbow elevation, local ice-packing therapy (3x/day), and an arm sling. Dressings were changed regularly. Daily functional exercises began with passive range of motion exercises outside the sling, followed by active range of motion exercises, as the standard treatment protocol in consultation with the physical therapy and rehabilitation specialists, who were also blind to the study. Two years after surgery, patients meeting the inclusion criteria were called for a final follow-up and postoperative MEPS administration. Proprioceptive testing was conducted on the qualifying 15 patients and 15 controls using a technique devised to minimize visual and inter-participant interference biases on proprioceptive tasks.

2.4. Proprioception testing protocol

None of the patients had elbow pain at the time of the study. Evaluation of elbow function for patients and controls included MEPS, as an elbow specific functional outcome measure, and isokinetic dynamometer active and passive proprioceptive matching tasks. Elbow proprioception evaluation tests (passive joint repositioning of target angles and active target matching) were measured

Fig. 1. Proprioceptive testing setting at 90° of flexion, neutral position.

for two sessions in the arthroscopy group as well as in the control group using an isokinetic dynamometer (Cybex HUMAC® NORMTM Testing & Rehabilitation System, USA). Each session was composed of five repeating measurements. Results of the MEPS were also obtained from both groups after each session by two experienced sports medicine research assistants working independently from each other and blind to the study.

The passive repositioning test was performed using the continuous passive motion (CPM) mode of the Cybex HUMAC® NORMTM machine at 1°/second angular velocity. After teaching the target tasks to the participants, the tests were repeated five times in each of the two measurement sessions. The deviation values represent the patients' mean angular deviations from target flexion points of 60° and 120° [21]. The active test was performed in the same way along with active teaching, and repositioning matches without using the CPM function. From 90° of flexion, which is the neutral position to initiate the testing process (Fig. 1), two different target points were chosen: 30° of elbow extension (60° flexion from 0°) and followed by an additional 30° of elbow flexion (120° flexion from 0°), (Fig. 2). For both patient and control groups, all the measurements, data recording and outcome measures were performed independently by two research assistants, yielding two sets of data for each participant. In order to prevent any visual stimuli bias, all individuals in the groups were blindfolded during the tests. The hands, forearms, elbows and arms of the individuals were stabilized in a standard neutral position by grasping the proprioception testing handle of the isokinetic dynamometer. Separate entrance and exit doors to the testing room were utilized in order to prevent any interference between subjects.

2.5. Statistical analysis

The means of the two measurement sessions were calculated to obtain final data for the outcome measures as well as for the MEPS. A Kolmogorov-Smirnov test was performed for normal distribution of the data. The t-test was used for comparing independent samples of the groups and $p < 0.05$ was considered statistically significant. Passive joint repositioning and active target matching results are presented as positive or negative angular standard deviations from the tested target points, respectively represented by plus or minus values in Tables 1 and 2.

3. Results

The mean age for the arthroscopy group was 45.1 ± 6.4 years. The mean age for the control group was 40.7 ± 6.5 years. Minimum

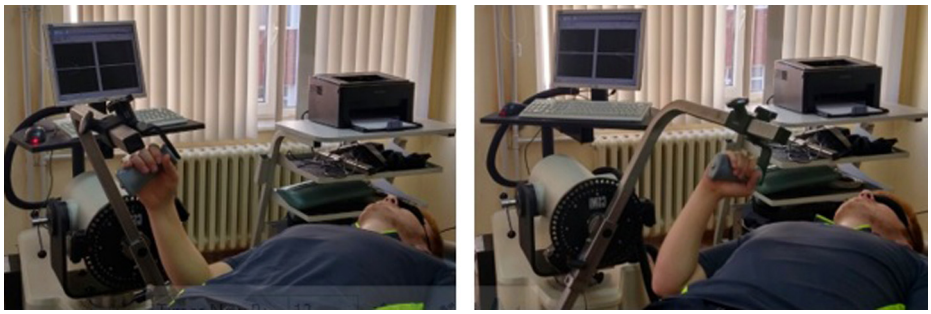

Fig. 2. Proprioceptive testing for passive joint position sense at 30° of extension (60° flexion from 0°) and 30° of flexion (120° flexion from 0°).

Table 1
Passive elbow joint proprioception constant error values (mean ± SD).

	Operation group (n = 15)	Control group (n = 15)	p value
@ 60° flexion	1,2 ± 4,9	−0,3 ± 2,8	0,5
@ 120° flexion	−3,9 ± 4,1	−0,2 ± 2,6	0,02

Table 2
Active elbow joint proprioception constant error values (mean ± SD).

	Operation group (n = 15)	Control group (n = 15)	p value
@ 60° flexion	−0,3 ± 7,4	−0,2 ± 0,1	0,4
@ 120° flexion	0,7 ± 5,9	−0,02 ± 1,6	0,8

Table 3
Demographics data (mean ± SD).

Parameters	Operation group (n = 15)	Control group (n = 15)	p value
Age (years)	45.1 ± 6.4	40.7 ± 6.5	0.15
Height (cm)	168.2 ± 10.2	166.4 ± 6.3	0.54
Weight (kg)	76.2 ± 9.5	78.1 ± 10.2	0.54

Table 4
Preoperative and postoperative MAYO elbow performance score outcome (mean ± SD).

	Preoperative	Postoperative	p value
MAYO Elbow Performance Score	51.67 ± 9.386	95.67 ± 6.779	0.001

follow up was two years. There was no statistically significant demographic difference between arthroscopy treated and control groups ($p > 0.05$), (Table 3).

All patients had improved elbow function, and had returned to their daily activities six weeks and their high demand works twelve weeks after surgery. All patients returned to their pre-injury activity level six months after surgery. None of the patients had elbow pain. Passive joint repositioning and active target matching results for the arthroscopy group and the control group are presented in Table 1 and Table 2 respectively. MEPS scores significantly increased in all arthroscopy patients two years after surgery (Table 4).

Passive joint repositioning outcome measurements of the arthroscopy group displayed deviations similar to the control group. A significant difference between the groups was only observed for the passive joint position sense at 120° of flexion. At this angle, the arthroscopy group showed greater deviation from target angles than the control group (p: 0.02). No significant differences were found among any other angles when compared to the control group in the active and passive tasks.

4. Discussion

Our literature review found no previous studies on proprioception after arthroscopic ECRB release surgery for chronic lateral epicondylitis, which led to our interest in studying this topic. In our study, outcomes of arthroscopic surgery for chronic lateral epicondylitis with no decortication yielded measurements similar to those of healthy controls. The sole significant difference was passive joint repositioning at 120° of flexion, where our data indicated greater negative angular deviations when compared to controls. This difference may be due to the effects of arthroscopic ECRB release surgery. The ECRB muscle has an additional minor elbow flexion function, and therefore acts as a neurophysiologic elbow flexion-extension angular detection apparatus. The arthroscopic ECRB release procedure loosens this muscle and impairs its mechanoreceptors, resulting in a lower threshold limit forsensing normal elbow flexion angles. Thus, throughout elbow flexion tasks, the surgically loosened ECRB muscle spindles and tendon mechanoreceptors responsible for proprioceptive sensings end premature signals for ECRB relaxation. By creating a premature "Stop!" signal to the brain, the command to the released ECRB muscle led the arthroscopy group participants to detect the target angle point prematurely due to a position-sensing illusion. Additional studies would help elucidate the mechanism behind these findings.

In addition to evaluating the proprioceptive outcomes of arthroscopic ECRB release in chronic lateral epiconydilitis, we developed a novel method for measuring proprioception after elbow surgery. Eliminating visual feedback via blind folding during testing refined our ability to detect actual proprioceptive impairment with greater sensitivity. Previous research has studied visual input amongst other factors affecting proprioception, and was mostly performed on healthy elbows [16,18–20]. The study by Juul-Kristensen et al. Used blind folding during proprioception testing, but only investigated patients who had not had surgery for lateral epicondylitis [4]. Several studies investigated the clinical outcomes in patients after surgery for lateral epicondylitis, but did not assess proprioception [12–15]. We are proposing that our novel proprioception testing method is accurate and reliable and believe that it could be of use to prospective studies on impaired elbows.

Our findings, methods, and proposed biomechanical explanation for impaired proprioception have implications for future treatment of elbow injuries that could potentially extend into patient education, surgery preparation, post-surgical self-care and re-injury prevention.

Limitations of the study included the use of a small sample size. This was due to our institution's strict Standard for proprioceptive testing inclusion criteria and threshold to include a reliable level of high upper limb activity demand individuals. Other limitations included a high threshold for proprioceptive testing inclusion eligibilty.

Few studies focus on healthy elbow proprioception, and very few proprioception studies address injured and surgically treated elbows. This study compares preoperative and postoperative MEPS results, along with postoperative proprioceptive outcome measures between the arthroscopic ECRB released and healthy control arms. Our review of the relevant recent literature led to the conclusion that we needed to refine the measurement techniques and treatment of elbow proprioception deficits among post-arthroscopy patients. The data and recommendations offered in this study have the potential to provide a simple, effective way to measure proprioception while reducing cofounding bias, and may serve as aspring board for future research.

Blind folding and utilizing separate entrance and exit door scan reduce visual and inter-individual bias, yielding more reliable and accurate results of elbow proprioceptive testing.

When matched to controls, outcomes for injured elbows two years post-surgery, using our proposed proprioceptive testing method, confirmed the long-term functional success of arthroscopic ECRB release with no decortication for the treatment of chronic lateral epicondylitis. The single proprioceptive deficit we found in post-surgical patients has a biomechanical explanation inherent to current implementation of ECRB release. This has immediate implications for surgical decision and post-surgical care, and could conceivably lead to refinements to this established and generally successful surgical technique. Further research may expand the applicability of proprioceptive measurement in evaluation, treatment, and recovery of upper-limb injuries, and even give rise to preventive strategies for proprioceptive decline among the various populations involved in high-demand upper extremity activities.

5. Conclusion

Postoperative proprioception measured in patients after arthroscopic ECRB release for chronic lateral epicondylitis with no decortication revealed similar outcomes to those of healthy controls. Higher angular deviations were only found in passive joint repositioning at 120° of flexion. This may be due to the loosening of the ECRB muscle spindles or impairement of the tendon mechanoreceptors of ECRB due to ECRB tendon release, which we postcreates early relaxation of the ECRB muscle causing it to detect the target angle prematurely due to altered proprioception.

Key points

Finding: active and passive joint repositioning outcome measurements were similar between patients and healthy participants. No significant differences were found among any angles except one: passive joint position sense at 120° of flexion.

Implications: patient must practice especially at 120° flexion passive joint repositioning after the elbow arthroscopy treatment.

Caution: our study results and specific proprioception method may have implications for improving accuracy of future elbow arthroscopy and proprioceptive recovery in this population.

Ethical approval

The study protocol was approved by the Medical Ethics Committee of the Suleyman Demirel University in Isparta, the Turkey.

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. This study was oral-presented at the 17th ESSKA Congress, 4–7 May 2016 held in Barcelona, Spain.

Disclosure of interest

The authors declare that they have no competing interest.

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Contribution

The conception: MU.
Design of the study: MU, CC, SE, OS.
Patient follow up: MU, OD, CC, SE, OS, HMD.
Acquisition of data: HMD, SE, OS, OD, CC.
Analysis and interpretation of data: SE, OS, HMD, CC, MU, AB.
Drafting the article: MU, AB, SE.
Revising it critically for important intellectual content: All authors.
Final approval of the version to be submitted: All authors.

References

[1] WaseemM, Nuhmani S, Ram CS, Sachin Y. Lateral epicondylitis: a review of the literature. J Back Musculoskelet Rehabil 2012;25:131–42.
[2] Cohen MS, Romeo AA. Lateral epicondylitis: open and arthroscopic treatment. J Am SocSurg Hand 2001;1:172–6.
[3] Harrington JM, Carter JT, Birrell L, Gompertz D. Surveillance case definitions for work related upper limb pain syndromes. Occup Environ Med 1998;55:264–71.
[4] Juul-Kristensen B, Lund H, Hansen K, Christensen H, Danneskiold-Samsøe B, Bliddal H. Poorer elbow proprioception in patients with lateral epicondylitis than in healthy controls: a cross-sectional study. J Shoulder Elbow Surg 2008;17:72–81.
[5] Ribeiro F, Mota J, Oliveira J. Effect of exercise-induced fatigue on position sense of the knee in the elderly. Eur J Appl Physiol 2007;99:379–85.
[6] Fortier S, Basset FA. The effects of exercise on limb proprioceptive signals. J Electromyogr Kinesiol 2012;22:795–802.
[7] Morrey BF. Surgical failure of tennis elbow. In: Morrey BF, Sanchez-Sotolo J, editors. The elbow and its disorders. 4th ed. Philadelphia: Saunders/Elsevier; 2009. p. 650–7.
[8] Calfee RP, Patel A, DaSilva MF, Akelman E. Management of lateral epicondylitis: current concepts. J Am Acad Orthop Surg 2008;16:19–29.
[9] Boyd HB, McLeod AC. Tennis elbow. J Bone Joint Surg Am 1973;55A:1183–7.
[10] Coonrad RW, Hooper R. Tennis elbow: its course, natural history, conservative and surgical management. J Bone Joint Surg Am 1973;55A:1177–82.
[11] Nirschl RP, Pettrone FA. The surgical treatment of lateral epicondylitis. Bone Joint Surg Am 1979;61:832–9.
[12] Wada T, Moriya T, Iba K, Ozasa Y, Sonoda T, Aoki M, et al. Functional outcomes after arthroscopic treatment of lateral epicondylitis. J Orthop Sci 2009;14:167–74.
[13] Grewal R, MacDermid JC, Shah P, King GJ. Functional outcome of arthroscopic extensor carpi radialis brevis tendon release in chronic lateral epicondylitis. J Hand Surg Am 2009;34:849–57.
[14] Peart RE, Strickler SS, Schweitzer Jr KM. Lateral epicondylitis: a comparative study of open and arthroscopic lateral release. Am J Orthop. (Belle Mead NJ) 2004;33:565–7.
[15] Kim JW, Chun CH, Shim DM, Kim TK, Kweon SH, Kang HJ, et al. Arthroscopic treatment of lateral epicondylitis: comparison of the outcome of ECRB release with and without decortication. Knee Surg Sports Traumatol Arthrosc 2011;19:1178–83.
[16] Juul-Kristensen B, Lund H, Hansen K, Christensen H, Danneskiold-Samsøe B, Bliddal H. Test-retest reliability of joint position and kinesthetic sense in the elbow of healthy subjects. Physiother Theory Pract 2008;24:65–72.
[17] Goble DJ, Brown SH. The biological and behavioral basis of upper limb asymmetries in sensorimotor performance. NeurosciBiobehav Rev 2008;32:598–610.
[18] Goble DJ, Brown SH. Upper limb asymmetries in the matching of proprioceptive versus visual targets. J Neurophysiol 2008;99:3063–74.

[19] Goble DJ, Brown SH. Dynamic proprioceptive target matching behavior in the upper limb: effects of speed, task difficulty and arm/hemisphere asymmetries. Behav Brain Res 2009;200:7–14.
[20] Goble DJ, Noble BC, Brown SH. Where was my arm again? Memory-based matching of proprioceptive targets is enhanced by increased target presentation time. NeurosciLett 2010;481:54–8.
[21] Gauthier A, Davenne D, Martin A, Van Hoecke J. Time of day effects on isometric and isokinetic torque developed during elbow flexion in humans. Eur J Appl Physiol 2001;84:249–52.