Eur J Appl Physiol (2006) 97: 613–618
DOI 10.1007/s00421-006-0231-8

ORIGINAL ARTICLE

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Shoulder muscle strength in paraplegics before and after kayak ergometer training

Accepted: 7 May 2006 / Published online: 10 June 2006

Abstract The purpose was to investigate if shoulder muscle strength in post-rehabilitated persons with spinal cord injury (SCI) was affected by kayak ergometer training and to compare shoulder strength in persons with SCI and able-bodied persons. Ten persons with SCI (7 males and 3 females, injury levels T3–T12) performed 60 min kayak ergometer training three times a week for 10 weeks with progressively increased intensity. Maximal voluntary concentric contractions were performed during six shoulder movements: flexion and extension (range of motion 65°), abduction and adduction (65°), and external and internal rotation (60°), with an angular velocity of 30° s^{-1}. Position specific strength was assessed at three shoulder angles (at the beginning, middle and end of the range of motion) in the respective movements. Test–retests were performed for all measurements before the training and the mean intraclass correlation coefficient was 0.941 (95% CI 0.928–0.954). There was a main effect of kayak ergometer training with increased shoulder muscle strength after training in persons with SCI. The improvements were independent of shoulder movement, and occurred in the beginning and middle positions. A tendency towards lower shoulder muscle strength was observed in the SCI group compared to a matched reference group of able-bodied persons. Thus, it appears that post-rehabilitated persons with SCI have not managed to fully regain/maintain their shoulder muscle strength on a similar level as that of able-bodied persons, and are able to improve their shoulder muscle strength after a period of kayak ergometer training.

Keywords Spinal cord injury · Isokinetic strength · Shoulder joint · Exercise · Training

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Introduction

Maintaining an adequate shoulder muscle function is essential for wheelchair users, such as persons with spinal cord injury (SCI). Every-day activities, such as wheelchair propulsion uphill and over obstacles and lifting and handling heavy loads, put high demands on upper body strength and stabilization. Moreover, inadequate shoulder muscle strength has been coupled to the frequent occurrence of shoulder pain among persons with SCI (Lee and McMahon 2002). When choosing a training activity for improving shoulder muscle function in general, and shoulder muscle strength in particular, it becomes important to consider an activity that stimulates a gain in shoulder muscle strength without, in itself, provoking overuse symptoms and shoulder pain (cf. Gellman et al. 1988; Burnham et al. 1993). Kayaking, either on open sea (Grigorenko et al. 2004; Bjerkefors et al. 2005) or on a kayak ergometer (Bjerkefors and Thorstensson 2006) appears to constitute such an activity, although effects on shoulder muscle strength have yet to be documented.

Training induced changes in shoulder muscle strength have been investigated in previous studies using a variety of methods for training and evaluation. Davis and Shephard (1990) studied the effects of arm ergometer training with different intensities and durations, but showed only limited effects on shoulder muscle strength. Yim et al. (1993) demonstrated a specific increase in shoulder flexion strength after progressive wheelchair ergometer training. Nilsson et al. (1975) and Hicks et al. (2003) both evaluated the effects of arm ergometer training plus additional weight training exercises and reported augmented shoulder strength in most of the one repetition maximum exercises tested. Jacobs et al. (2001) studied the effects of a circuit resistance-training program including both weight training performed in machines and arm ergometer training. They observed improvements in isokinetic shoulder muscle strength in movements in all three planes, except shoulder flexion and external rotation.

A relevant factor to consider in this context is the initial strength level possessed by the persons with SCI, e.g. in relation to that of able-bodied non-athletes. Studies comparing SCI and able-bodied have, however, reported varying results. Pentland and Twomey (1994) investigated the average torque during isokinetic shoulder movements in flexion, extension and adduction, and found that persons with SCI were weaker in shoulder flexion compared to able-bodied persons. Powers et al. (1994) measured shoulder elevation in the scapular plane and internal and external rotation of the shoulder, and reported lower isometric torque values in internal rotation compared to able-bodied. Kotajarvi et al. (2002) studied the isometric mean peak torque in all three planes, and found no differences between persons with SCI and able-bodied persons.

Previously we have shown that a 10-week training program on kayak ergometer had significant positive carry-over effects on strength related functional tasks performed in the wheelchair, such as propelling uphill, mounting a platform and transferring from the wheelchair to a plank bed (Bjerkefors and Thorstensson 2006). Now, the purpose was, therefore, to study maximal voluntary shoulder muscle strength in these post-rehabilitated persons with SCI, before and after a 10-week period of kayak ergometer training, taking into account its dependency on movement direction in three dimensions and position in the range of motion, and, in addition, to compare their strength characteristics with those of a matched reference group of able-bodied persons. The hypotheses were that the persons with SCI would have lower initial strength and that it would improve with the kayak ergometer training.

Methods

Subjects

Ten persons with SCI, levels ranging from T3 to T12, volunteered for the study (7 M and 3 F; 38 ± 12 years, 1.76 ± 0.09 m, 70.8 ± 13.9 kg). Years post injury varied from 3 to 26 (median 11.5) and sensory scores (pin prick and light touch, maximal score 112 = unimpaired function, Maynard et al. 1997) from 37 to 90 (median 58). Seven persons had a complete injury (ASIA "A"), and three an incomplete impairment (two ASIA "B", and one "C", respectively, Maynard et al. 1997). The level of habitual physical activity, i.e. outside the training protocol, varied within the group, but did not change markedly over the training period. A reference group (R) of 10 able-bodied persons with similar body measures was recruited among the laboratory personnel (7 M and 3 F; 35 ± 10 years, 1.77 ± 0.08 m and 76.5 ± 12.7 kg). The reference group took part only in the strength tests and not in the training. All subjects gave their informed consent to participate before the start of the study. The study was approved by the Ethical Committee of the Karolinska Institutet.

Training equipment and procedure

A commercially available kayak ergometer (Dansprint, I Bergmann A/S, DK) was modified with an additional custom-built balance module, which made it possible to regulate the balance demand in the medio-lateral direction (Bjerkefors and Thorstensson 2006). The balance demand was individually adjusted to each subject's initial ability to cope with the instability during the paddling movement. To secure the sitting position a special kayak seat with adjustable back and footrest (Grigorenko et al. 2004) was mounted onto the kayak ergometer.

Subjects paddled three times a week during a 10-week-period. All subjects completed the entire program as planned, i.e. 30 training sessions. Each session lasted approximately 60 min and included a warm-up, interval training (2–8 min work and 1–2 min rest), and a cool-down. Instructors supervised all sessions. During the first three sessions, subjects were taught paddling technique. After this familiarization, the balance demand and the training intensity were progressively increased during the training period (Bjerkefors and Thorstensson 2006).

Test equipment and procedure

Shoulder muscle strength (torque) measurements were performed using an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, USA). Subjects were seated in an experimental chair (Biodex) with the backrest tilted at 85°. To prevent trunk movement during testing, the upper body was secured with Velcro straps across the subject's chest and pelvis. Torque was assessed during maximal voluntary concentric contractions in six different movements of the right shoulder: flexion and extension, abduction and adduction, and external and internal rotation, respectively. The angular velocity was set at $30° s^{-1}$.

Shoulder flexion and extension (range of motion, ROM, 65°, between 50° of flexion and 15° of extension) were performed with the shoulder in 15° of abduction and with the elbow in an extended position. Shoulder abduction and adduction (ROM 65°, between 70° and 5° of abduction) were carried out with an extended elbow. In abduction and adduction, as well as in flexion and extension, the elbow was maintained in an extended position by an orthoplastic splint. External and internal rotation (ROM 60°, between 45° of external rotation and 15° of internal rotation) were performed with the shoulder in

15° of abduction and with the elbow in 90° of flexion, and the forearm secured in a supporting cuff. In all tests, subjects were applying torque to a handle. Wrist movements were prevented by a rigid brace. The left hand was placed on the chest. Prior to the test subjects performed 5 min of wheelchair propelling on level surface as a general warm-up.

Strength measurements were performed in three identical sets, one for each combination of movements around the same axis, first flexion and extension, then abduction and adduction and last external and internal rotation, respectively. Each set started with a specific warm-up consisting of 30 s of alternating sub-maximal contractions at 90° s^{-1}. Then followed four maximal contractions in each direction, performed in an alternating fashion and interspersed by a rest period of 4 s between each contraction. A 2 min break was allowed between sets of contractions. Subjects were instructed, and verbally encouraged, to exert maximal voluntary effort during the whole range of each motion.

Torque values were analysed at three specific angular positions in each of the six shoulder movements: in the beginning, in the middle, and at the end of the total range of motion. The specific angular positions were: for shoulder flexion and extension: 3° of extension and 17.5 and 38° of flexion; for shoulder abduction and adduction: 17, 37.5 and 58° of abduction; and for shoulder external and internal rotation: 5° of internal rotation, and 15 and 35° of external rotation, respectively. Each position occurred during the isokinetic (constant angular velocity) phase of the movement, as illustrated in Fig. 1. The highest value at each specific angular position for each movement was used in the statistical analysis.

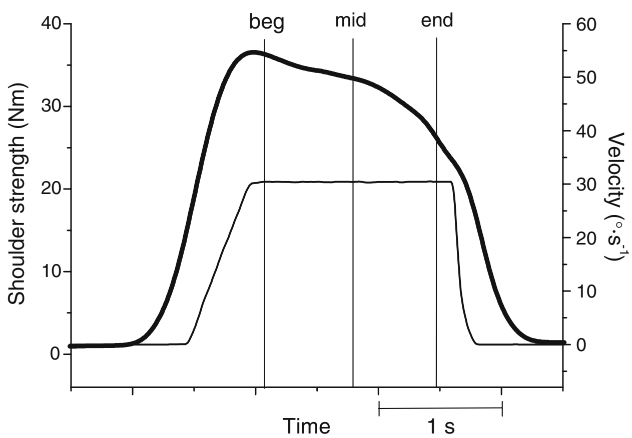


Fig. 1 Representative recordings of shoulder muscle strength (torque in Nm, *thick line*) and angular velocity (° s^{-1}, *thin line*) from one subject during a single maximal voluntary contraction in shoulder external rotation with an angular velocity of 30° s^{-1}. *Vertical lines* denote the three shoulder angles at which the position specific torque was determined, i.e. at the beginning (*beg*), middle (*mid*) and end (*end*) of the range of motion. (See Methods for exact angles.) Note that the experimental paradigm allowed for isometric torque to be produced before the start of the movement, i.e. the rise of the torque preceded that of the velocity

Test–retests were performed on two separate days (at the same time of the day), 1 week apart, before the training began in the SCI group. Establishing a baseline pre-training level with a test–retest protocol became essential since it was not possible to recruit a matched control group with SCI.

Statistics

The statistics were carried out in Statistica 7.0 (StatSoft, USA). Shapiro-Wilk's W test was applied to examine normality in the distribution of data. To estimate the test–retest reliability, intraclass correlations ($ICC_{2,1}$) were calculated between before training values (T1 vs. T2) for persons in the SCI group. To detect differences between before and after training in the SCI group, torque values were analyzed using a three-way analysis of variance (ANOVA), with the factors: training (T2 and T3), × movement (flexion, extension, abduction, adduction, external rotation and internal rotation) × position (in the beginning, in the middle, and at the end of the range of motion). Significant interaction effects were analyzed further using pre-planned comparisons. To determine differences between the SCI group before training and the reference group (R), torque values were analyzed using a three-way ANOVA, with the factors: group (T2 and R) × movement × position. If the data did not conform to the assumption of sphericity the P values was Greenhouse–Geisser corrected. Significance of differences was determined at $P < 0.05$ and tendencies were identified at $0.05 \leq P < 0.1$.

Results

Test–retest

The average intraclass correlation coefficient for test–retest torque values in the SCI group before training was 0.941 (95% CI 0.928–0.954).

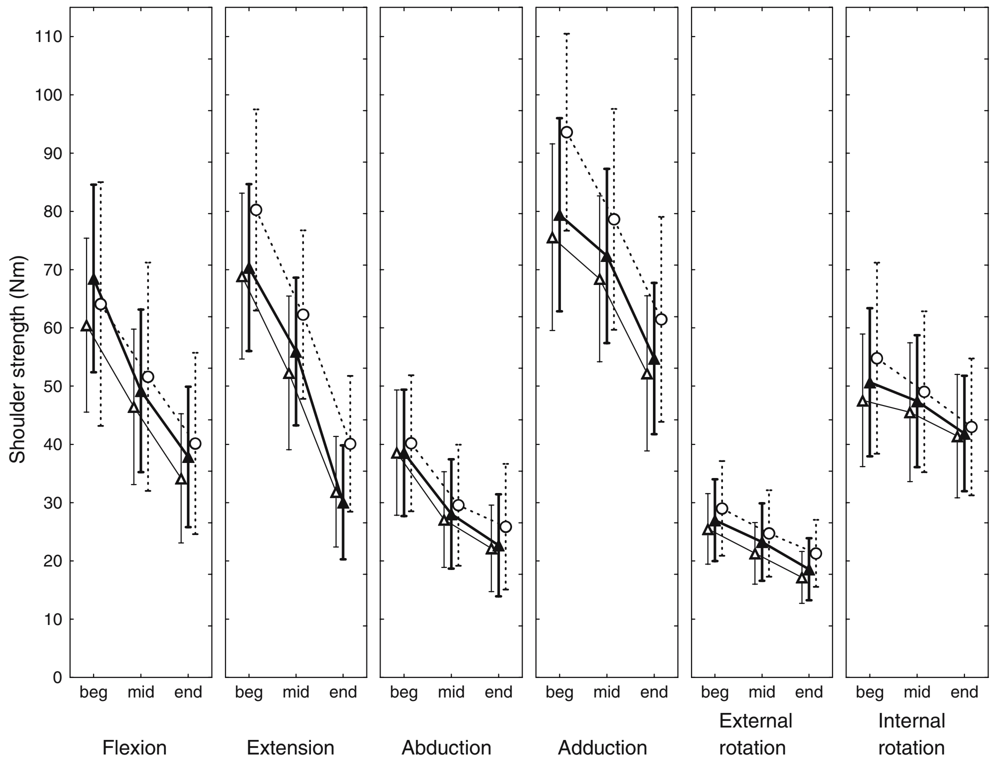
After versus before training (Fig. 2)

There was a main effect of training with increased shoulder muscle strength after training in the SCI group [$F_{(1, 9)} = 7.54$, $P = 0.023$]. There was no interaction between training, movement and position [$F_{(10, 90)} = 2.00$, $P = 0.128$], or between training and movement [$F_{(5, 45)} = 1.65$, $P = 0.166$], but an interaction was present between training and position [$F_{(2, 18)} = 9.07$, $P = 0.004$]. Pre-planned comparisons showed significant training effects in the beginning [$F_{(1, 9)} = 12.81$, $P = 0.006$] and in the middle positions [$F_{(1, 9)} = 7.23$, $P = 0.025$] in the range of motion.

SCI versus R (Fig. 2)

Analysis for a main effect between groups indicated lower shoulder muscle strength in the SCI group compared to

Fig. 2 Least Squares Means and 95% confidence intervals for shoulder muscle strength (Torque, Nm) at the angular velocity of 30° s^{-1} for the group of persons with SCI before (T2, *open triangles*) and after training (T3, *filled triangles*) and for the matched reference group (*R*) of able-bodied persons (*open circles*), during six shoulder movements: flexion, extension, abduction, adduction, external and internal rotation, at three shoulder angles: at the beginning (*beg*), middle (*mid*) and end (*end*) of the range of motion (cf. Fig. 1). Values for the respective shoulder angles are given in Methods



the R; this difference approached but did not reach conventional levels of significance [$F_{(1, 9)} = 3.87$, $P = 0.081$]. There was no interaction group × movement × position [$F_{(10, 90)} = 1.65$, $P = 0.210$]. An interaction between group and movement approached but did not reach conventional levels of significance [$F_{(5, 45)} = 2.12$, $P = 0.081$]. There was no interaction between group and position [$F_{(2, 18)} = 1.37$, $P = 0.279$].

Discussion

Kayak ergometer training was shown to provide enough training stimulus to cause improved maximal voluntary shoulder muscle strength, as evidenced by the various isokinetic strength tests applied, in persons with SCI. It is also worth noticing that the extra load on the upper body, induced by the rather intense kayak ergometer training, did not lead to any shoulder problems or other overload symptoms.

Kayak ergometer training was chosen as a training protocol because of its accessibility for persons with SCI as well as for its potential to engage most of the musculature of the upper body. The training was not particularly aimed at improving muscle strength, but to mimic a leisure activity with an intensity that might be enough to stimulate both strength and endurance for this particular category of persons. The subjective experience from the trainees was generally positive, including positive effects on general life quality, shoulder muscle strength, cardiovascular fitness, and upper body stability (Bjerkefors and Thorstensson 2006). In addition, improvements with training were noted in performance of functional test, which, at least to some extent appeared to involve strength of the shoulder muscles, such as mounting a platform, propelling the wheelchair uphill, and transfer the body to an elevated bed (Bjerkefors and Thorstensson 2006).

Other studies of training effects on shoulder strength include Davis and Shephard (1990), who investigated eleven wheelchair users after a 16-week training program of arm ergometer training. Strength test was performed in shoulder flexion, abduction and adduction, and elbow flexion and extension. Improvements were reported only in elbow extension after training. Yim et al. (1993) followed the effects of a 5-week period of wheelchair ergometer training in a group of six paraplegics. Shoulder muscle strength was measured in flexion and extension, respectively, with gains present only in shoulder flexion torque after training. The effect of training with arm ergometer plus additional resistance exercises was investigated by Hicks et al. (2003), who included eleven subjects with tetraplegia and paraplegia in a 9-month training program. Strength performance was measured during chest press, and in shoulder and elbow flexion, bilaterally. There were improvements from 19 to 34% in five out of the six tests after the training. In a study by Jacobs et al. (2001) ten subjects with SCI participated in a 12-week circuit-training program. The program consisted of arm ergometer training followed by six different resistance manoeuvres performed in a “circuit” procedure. Shoulder strength measurements were done both in strength performance tasks and during maximal isokinetic contractions. The training had positive effects in five out of six strength performance tasks, and in four out of six shoulder movements during concentric contractions (the exceptions were shoulder flexion and external rotation). Training on arm and wheelchair ergometers alone, i.e. without any additional weight training exercises, appears to cause limited improvements in shoulder strength with respect to magnitude and movement direction. In contrast, kayak ergometer training as performed here required a high enough level of force to stimulate mechanisms underlying a strength gain in post-rehabilitated persons with SCI. Furthermore; this type of training appears to be sufficiently versatile to lead to strength gains in all shoulder movements in all three planes. This versatility may also underlie the apparent leniency on structures surrounding the shoulder joint.

Another factor to consider in this context is that the initial level of the trainees might play a role in the adaptation to training. In the strength training literature it is generally accepted that a lower initial proficiency allows for a larger and faster gain in strength with training (e.g. Kraemer et al. 2002). The persons with SCI in the present study were all in a post-rehabilitation stage with a varying, but on the average rather long, time since injury. In comparison to the matched reference group of able-bodied persons, the persons with SCI demonstrated a tendency towards lower strength levels. Lack of statistical significance prohibited further analysis of possible movement and position specific differences. Such differences, have, however, been studied before. Kotajarvi et al. (2002) measured isometric shoulder strength in all three planes in paraplegics, and found no differences between persons with SCI and able-bodied persons. Similar values for isometric shoulder strength have also been reported in paraplegics and able-bodied persons for shoulder elevation, and external rotation (Powers et al. (1994). Lower strength values for internal rotation in the paraplegic group were related the test set-up, where lack of trunk stabilization might have affected the possibilities of the persons with SCI to produce at their maximum specifically during the internal rotation movement. Pentland and Twomey (1994) investigated shoulder flexion, extension and adduction during isokinetic contractions, and found that persons with SCI were weaker in shoulder flexion compared to able-bodied persons. They reason that this specific weakness might be partly explained by the high frequency of shoulder pain (39%) in the SCI group and that flexion should provoke more pain than the other movements. The lack of pronounced differences in shoulder muscle strength between persons with SCI and able-bodied persons, indicate that daily activities, such as wheelchair propulsion and transferring tasks, are not strength-building activities that improves the maximal strength in post-rehabilitated persons with SCI, at least not above the level of that of matched able-bodied persons. It is noteworthy that wheelchair paraplegic athletes, who participated in wheelchair sports on the average 13 h/week, showed a considerably higher shoulder strength (23–62%) than able-bodied athletes in all tested shoulder movements, i.e. abduction/adduction and external/internal rotation (Burnham et al. 1993).

The functional significance of the improvements in shoulder muscle strength after kayak ergometer training is indicated by the concomitant increases of the performance in several functional tests, e.g. mounting a platform (7%), transferring from the wheelchair to an elevated plank bed (10%), and propelling the wheelchair uphill (6%) (Bjerkefors and Thorstensson 2006). Improvements of shoulder muscle strength may also provide better substrate for upper body stabilization and balance control in sitting, since shoulder muscles participate more in these tasks in paraplegics, lacking full control over trunk muscles, than able-bodied persons (Seelen et al. 1998). Training on the kayak ergometer can be graded within wide limits with respect to intensity and, in the current set-up, balance demand. Using a more intense training regime than that used here can be expected to cause even larger improvements in strength and strength related performance.

Acknowledgments We thank the Swedish Inheritance Fund and the Swedish Center of Sport Research for financial support and Rekryteringsgruppen for Active Rehabilitation for initiating and continuously supporting the project. Special thanks are due to the participants and to the instructors (Mats-Erik Bjerkefors, Micka Hahne, Gunnar Krantz, and Ulla Löfquist), who made the training and the testing period a pleasant and rewarding time for all involved. Finally, we would like to thank Benny Setterberg, Leif Wahlstedt and Samuel Karlsson for the excellent collaboration and contribution to the development of the adjustable balance module on the kayak ergometer, and Maria Ekblom (formerly Nordlund) for her valuable comments on the manuscript.

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