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Strength Profiles of Shoulder Rotators in Healthy Sport Climbers and Nonclimbers

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Objective: To establish the isokinetic strength profiles and work ratios of the shoulder internal and external rotators in sport climbers and to compare them with these profiles and ratios in nonclimbers. We hypothesized that the strength profiles of the shoulder rotators were different between sport climbers and nonclimbers.

Design: Cross-sectional study.

Setting: Exercise science laboratory.

Patients or Other Participants: Thirty-one experienced sport climbers and 27 nonclimbers.

Main Outcome Measure(s): We tested all participants by measuring the isokinetic concentric and eccentric work output of their shoulder rotators in the middle 110° of shoulder rotation. We measured mean conventional work ratios of concentric external rotation (ER) to internal rotation (IR) (con ER:IR) and eccentric ER to IR (ecc ER:IR), and we measured mean functional work ratios of eccentric ER to concentric IR (ecc ER:con IR) and eccentric IR to concentric ER (ecc IR:con ER).

Results: All work ratios were different between the 2 groups ($P < .001$). In the climbers, the conventional work ratios were smaller than 1 for con ER:IR (0.79) and ecc ER:IR (0.88), whereas for the nonclimbers, the ratios were 1.03 and 1.13, respectively. The functional work ratio of ecc ER:con IR was smaller for the climbers (1.05) than for the nonclimbers (1.30), but the functional work ratio of ecc IR:con ER was larger for the climbers (1.58) than for the nonclimbers (1.17).

Conclusions: The difference in work ratios of the shoulder rotators between participant groups might be due to training-induced changes in the shoulder rotation muscles of sport climbers. The clinical implication of this strength difference in shoulder IR and ER in climbers has yet to be examined.

Key Words: isokinetic tests, training

Key Points

- Normalized work of shoulder internal and external rotators was greater in climbers than in nonclimbers because the climbers likely had well-developed shoulder muscles as a result of the greater demands placed on the upper limbs.
- The conventional work ratios of concentric external rotation to internal rotation and eccentric external rotation to internal rotation were lower in the climbers than in the nonclimbers.
- The functional work ratio of eccentric external rotation to concentric internal rotation was lower in the climbers than in the nonclimbers.
- The functional work ratio of eccentric internal rotation to concentric external rotation was higher in the climbers than in the nonclimbers, implying that the climbers had strong eccentric internal rotation.

Stability of the shoulder complex depends on the dynamic muscle balance.[1] Changes in the strength profile of the shoulder muscles may result in shoulder problems, especially in athletes who participate in overhead sports.[2,3] Comparing the isokinetic strength ratio of muscle groups antagonistic to each other may reveal muscle imbalances and, thus, may help to formulate a suitable muscle-training program.[4]

Isokinetic strength and work ratios of the shoulder for athletes involved in overhead sports have been studied, and researchers[5–9] have reported that these athletes have different strength profiles in their shoulder muscles than do nonathletes. This finding may have implications with regard to training and injury prevention in these athletes.

Sport climbing has been gaining popularity since the 1970s.[10–13] Wright et al[13] revealed a 40% increase in the number of rock-climbing participants from 1989 to 1993. Many international sport-climbing competitions are held, and inclusion of this sport as an event in the Olympic Games has been under consideration since the 1990s.[10] However, despite the popularity of sport climbing, few investigators have examined the science of this sport; thus, the training and rehabilitation of sport climbers are largely based on empirical experience rather than on scientific data.

The purpose of our study was to establish the isokinetic strength profiles and work ratios of shoulder internal and external rotators in experienced sports climbers and to compare these values with those of healthy, nonathletic participants. The establishment of these strength profiles in sports climbers will provide a baseline for coaches and therapists in the training and rehabilitation of these athletes. We hypothesized that the strength profiles of the shoulder rotators were different between sport climbers and nonclimbers.

METHODS

Participants

Thirty-one climbers (23 men, 8 women; age = 28.2 ± 7.4 years, height = 1.7 ± 0.08 m, mass = 59.0 ± 9.3 kg) from a local mountaineering union and 27 healthy, nonathletic people (14 men, 13 women; age = 33.1 ± 5.1 years, height

Table 1. Normalized Work Value of Shoulder Rotators Against the Body Mass of Participants and *t* Test Results for Between-Groups Comparisons (Mean ± SD)

Normalized Work	Climbers	Nonclimbers	t_{56}	*P*
Concentric internal rotation, J/kg	0.76 ± 0.25	0.42 ± 0.13	6.23	<.001
Concentric external rotation, J/kg	0.59 ± 0.17	0.43 ± 0.10	4.26	<.001
Eccentric internal rotation, J/kg	−0.89 ± −0.27[a]	−0.49 ± 0.16[a]	−6.72	<.001
Eccentric external rotation, J/kg	−0.75 ± 0.20[a]	−0.52 ± 0.14[a]	−5.09	<.001

[a] The negative sign indicates the opposite direction of eccentric force.

= 1.6 ± 0.07 m, mass = 59.8 ± 11.9 kg) voluntarily participated in our study. The climbers were experienced and active in the sport. They had practiced sport climbing for 6.0 ± 3.8 years, and their practicing frequency in the 2 years before the study included 3.4 ± 0.7 hours per session, 10.5 ± 3.0 hours per week, and 3.2 ± 0.8 days per week.

All participants gave their written informed consent, and the study was approved by The Hong Kong Polytechnic University Ethics Review Committee before testing. To enhance homogeneity and safety for isokinetic testing, all participants completed a screening questionnaire and were assessed for contraindications of isokinetic testing according to the method of Chan et al.[14]

Isokinetic Testing Protocol

The tests were conducted in a sport rehabilitation laboratory, and 1 participant was tested per time slot. The same investigator (E.K.L.W.) conducted the tests for all participants using an isokinetic testing system (Cybex Norm; Henley Healthcare, Nauppauge, NY). Before and after the tests, each participant followed a standard 10-minute warm-up and cool-down exercise procedure.

Each participant assumed the crook-lying position on the isokinetic testing couch, with the trunk secured by straps over the upper and lower chest. To minimize unintended movements, the participant held onto the handle of the couch with the other hand. The neutral position was set at 90° of shoulder abduction and 90° of elbow flexion so that the forearm was aligned to the vertical. The range of testing for external rotators was from the 60° internally rotated position to the 90° externally rotated position, and the range of testing for internal rotators was from the 90° externally rotated position to the 60° internally rotated position.

To determine the conventional and functional work ratios, we examined both concentric and eccentric work output of the shoulder rotators. The testing speed was set at 60°/s. Submaximal trials were performed before the tests so the participants could become familiar with the actions. Each test bout comprised 5 repetitions of external rotation (ER) and internal rotation (IR) movements. A standardized oral command was given to the participants to enhance the reliability and to facilitate their performance during the tests.

To avoid fluctuation of resistance at the beginning and end of tests due to "impulse loading," data for the initial and final 20° of range were excluded.[14,15] Therefore, the data used for analysis were collected in the middle 110° of shoulder rotation. The average work of 5 repetitions of each rotation action was calculated. To compare participants with different body builds, we calculated the work to body mass ratio (normalized work value).[4]

Data Analysis

We calculated both the average conventional and the average functional isokinetic work ratios of the participants.[8] Conventional work ratios were concentric work output of ER:IR (con ER:IR) and eccentric work output of ER:IR (ecc ER:IR). Functional work ratios were the work output of eccentric ER to concentric IR (ecc ER:con IR) and eccentric IR to concentric ER (ecc IR:con ER).[8]

Statistical Analysis

We used SPSS (version 11.5; SPSS Inc, Chicago, IL) to analyze the data. The means and SDs for the demographic data, normalized work, and conventional and functional work ratios were calculated. Two-tailed *t* tests for independent samples were used to compare the normalized work and conventional and functional work ratios between climbers and nonclimbers. The α level was set at .05 a priori for all statistical tests. To reduce type I error, we calculated Bonferroni adjustments with the α adjusted to .0125 (ie, .05/4) for normalized work and .025 (ie, .05/2) for both conventional and functional work ratios.

RESULTS

Two-tailed *t* tests for independent samples revealed that all the normalized work of external and internal rotators was different between the climbers and nonclimbers ($P <$ .001) (Table 1). The normalized work values of concentric IR and ER and of eccentric IR and ER were higher for the climbers than for the nonclimbers. The mean values of concentric IR and eccentric IR were 1.81 and 1.82 times higher, respectively, in the climbers than in the nonclimbers. The mean values of concentric ER and eccentric ER were 1.37 and 1.44 times higher, respectively, in the climbers than in the nonclimbers.

Results of the conventional work ratios of the shoulder rotators (con ER:IR and ecc ER:IR) were different between the 2 groups ($P \leq$ .001) (Table 2). The mean conventional work ratios were less than 1 for the climbers (con ER:IR = 0.79 and ecc ER:IR = 0.88) and more than 1 for the nonclimbers (con ER:IR = 1.03 and ecc ER:IR = 1.13).

The mean functional work ratios of ecc ER:con IR and ecc IR:con ER were different between the 2 groups ($P \leq$ .005) (Table 3). The ecc ER:con IR ratio was lower for the climbers (1.05) than for the nonclimbers (1.30), but the ecc IR:con ER ratio was higher for the climbers (1.58) than for the nonclimbers (1.17).

DISCUSSION

Little is known about the science of sport climbing because it is a relatively new sport. As with other overhead

Table 2. Conventional Work Ratios of Climbers and Nonclimbers and Results of Between-Groups Comparisons of the Ratios (Mean ± SD)

Conventional Work Ratio	Climbers	Nonclimbers	t_{56}	P
Concentric external rotation to internal rotation	0.79 ± 0.20	1.03 ± 0.24	−4.20	<.001
Eccentric external rotation to internal rotation	0.88 ± 0.19	1.13 ± 0.31	−3.63	.001

sports, the high demands placed on the shoulder during climbing would predispose the joint to injuries.[10–12,16–19] Therefore, by examining the training-induced muscle adaptations, we can provide a guideline for designing the training strategy and for preventing injuries. Our results revealed that both conventional and functional work ratios of the shoulder rotators were different between the climbers and nonclimbers ($P \leq .005$).

The findings of higher normalized work of shoulder internal and external rotators in the climbers are reasonable because given the heavy demands on the upper limbs, the shoulder muscles would be better developed in these athletes (Table 1). Our results also agreed with those of Ivey et al,[20] who found that individuals who exercised their upper limbs regularly had higher torque output than those who did not. During isokinetic testing, athletes involved in throwing sports have a tendency to recruit individual muscles in a much more selective and coordinated way than do untrained individuals.[1] A similarity between sport climbing and throwing sports is that both sports involve repeated overhead actions with shoulder movements of extension and IR. Therefore, the climbers might be able to perform the tests more smoothly and with better coordination than the nonclimbers.

The mean conventional work ratios of con ER:IR and ecc ER:IR for the nonclimbers were 1.03 and 1.13, respectively (Table 2). These findings were different from those of Ivey et al,[20] who found that the normal strength ratio of the con ER:IR was about 0.67. Our findings may differ because Ivey et al[20] measured strength ratio at a specific angle, whereas we referred to work ratios as a range of action. The findings of a roughly 1:1 ratio in all the conventional work in the nonclimbers might indicate that the shoulder external and internal rotators made similar contributions in both concentric and eccentric modes in daily activities.

As noted, both the conventional and functional work ratios of the climbers were different from those of the nonclimbers ($P \leq .005$). These differences could imply some training-induced adaptations in the shoulder muscles of the climbers. Table 2 shows that the mean conventional work ratios of con ER:IR and ecc ER:IR for the climbers were less than 1 and were lower than these ratios for nonclimbers. Because all the normalized work ratios for the climbers were higher than for the nonclimbers (Table 1), the only reason for the lower conventional work ratios in the climbers was the relatively higher work output of the internal rotators in this participant group.

The shoulder internal rotators are frequently used in sport climbing during the pull-up phase, which may explain the finding that the climbers had lower con ER:IR ratios than the nonclimbers. The findings were in line with the reports of Ellenbecker,[5,6] Ellenbecker and Mattalino,[7] and Bak and Magnusson,[9] who studied overhead athletes and found that the ratios of con ER:IR in most of the athletes were less than 1, which indicated that the shoulder internal rotators in the concentric mode had predominant contributions in the overhead-sport athletes and sport climbers.

The ecc ER:IR ratio was lower in the climbers than in the nonclimbers (0.88 and 1.13, respectively; $t_{56} = -3.63$, $P = .001$) (Table 2). This finding implied that the eccentric work output of IR was higher than that of ER. This may be due to the overflow of concentric training effect on eccentric muscle performance. The effect of concentric strength training is less mode specific, whereas eccentric strength training is highly mode specific. With concentric muscle training, both concentric and eccentric performances improve, whereas for eccentric training, the improvement is specific with the same mode of testing.[21–23] Therefore, when the concentric IR muscles are strengthened with the "body pull-up" action in climbing, the respective muscle work in the eccentric mode might also improve.

The functional work ratio of ecc ER:con IR signifies the work output from the 2 rotator muscle groups during the pull-up phase of climbing. During this phase, the internal rotators work concentrically to ascend the body, whereas the external rotators might work eccentrically to prevent excessive IR and also to provide compression on the shoulder for stabilization. This ratio was lower in the climbers than in the nonclimbers (1.05 and 1.30, respectively; $t_{56} = 2.92$, $P = .005$) (Table 3). In their study of badminton players, Ng and Lam[8] found that the shoulder ecc ER:con IR work ratios corresponded with the deceleration phase of smashing. The authors found a lower ratio in the dominant arm than in the nondominant arm of the players, and they suggested that it was due to the strong concentric work of IR, required during training for badminton. When considering the body pull-up phase in climbing, the prime muscle actions should be concentric shoulder extension, adduction, and IR. Because of the training adaptations for sport climbing, higher work output of concentric IR in the climbers would result and

Table 3. Functional Work Ratios of Climbers and Nonclimbers and Results of Between-Groups Comparisons of the Ratios (Mean ± SD)

Functional Work Ratio	Climbers	Nonclimbers	t_{56}	P
Eccentric external rotation to concentric internal rotation	−1.05 ± 0.27[a]	−1.30 ± 0.38[a]	2.92	.005
Eccentric internal rotation to concentric external rotation	−1.58 ± 0.49[a]	−1.17 ± 0.32[a]	−3.69	<.001

[a] The negative sign indicates the reverse direction of eccentric-to-concentric movement.

would explain the observed functional work ratio seen in this group.

The other functional work ratio was ecc IR:con ER, which resembled the action of raising the arm to an overhead position in preparation for the pull-up action. This ratio was higher in the climbers (1.58) than in nonclimbers (1.17) (Table 3). The high ratio implied that the climbers had strong eccentric IR. According to the normal pull-up action, involvement of eccentric IR should be minimal. We believe that the high eccentric strength in IR could be either an overflow training effect of the concentric IR, as stated, or a genuine requirement of strong eccentric IR in sport climbers, as reflected in the functional work ratio. Further studies on the biomechanics of sport climbing are needed to determine the muscle requirements of this sport.

According to Mayer et al,[24] deviations in the strength ratios are regarded as muscle imbalance, which has a negative connotation with regard to shoulder disorder. The "strength imbalance" can be determined by comparing the strength of one side with that of the contralateral side or with the values of a healthy population. The differences in isokinetic work ratios between climbers and nonclimbers indicated that natural, training-induced adaptations in the shoulder antagonist-agonist pairs had occurred in the climbers. We do not know if these altered muscle-strength profiles are harmful to the athletes. We suggest that researchers conduct a follow-up study to examine if climbers with shoulder problems have different isokinetic work ratios than those presented in our study, so that the effect of these muscle imbalances may be revealed.

CONCLUSIONS

Differences in conventional and functional work ratios of shoulder rotators were found between the climbers and the nonclimbers and may be due to training-induced adaptations in the sport climbers. We hope that information from this study can guide clinicians and coaches in planning quality rehabilitation and training programs for sport climbers.

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