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Correlation of forearm strength and sport climbing performance

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Abstract. The aim of the study was to determine whether forearm muscle strength correlates with sport climbing performance. Three different movements of the forearm musculature in 25 recreational climbers (performance on sight (os) style mean F7a+, range 6b+ – 7c; red point (rp) style 7b+, range 7a – 8b+) were examined. A special isokinetic device was built to investigate eccentric and concentric isokinetic maximum strength of wrist (wr) flexion, proximal interphalangeal joint (pi) flexion of the middle- and ringfinger and a "rolling in a bar" movement involving both interphalangeal joints and the metacarpophalangeal joint (ro) of all fingers. There was no correlation between absolute maximum strength and climbing performance. Relative strength (strength/body weight) of all three exercises however correlated significantly with climbing difficulty of rp and os style, except pi flexion and os style. Correlation coefficient was highest between rp and concentric wr flexion. Among forearm musculature concentric wrist flexion was the best predictor for sport climbing performance.

Keywords: Sport climbing, finger flexor, wrist flexor, maximum strength

1. Introduction

In the last 25 years sport climbing and in particular indoor climbing has become very popular. Due to relatively safe environments and an improvement in protective equipment, climbers have been able to focus increasingly on difficult and athletic climbing movements leading to a rise in the maximum grade of difficulty. The former UIAA (Union Internationale des Associations d'Alpinisme) scale which had spanned 6 grades was extended to include 11 grades (similar to French grade 9a). Sport climbing has become a competitive sport with an international annual indoor World cup. The style of modern sport climbing changed to steep, overhanging and athletic routes requiring mainly upper body and finger strength. The typical sport climber is generally characterised as being small in stature, light body weighted and with muscular upper body [6]. In order to characterize sport climbers and to assign the performance defining factors, several anthropometric studies have been performed [6]. It is commonly held by climbers that finger strength is one of the most limiting factors. Several studies have investigated maximum finger strength with somewhat controversial results [5,8,9,12,23]. Strength measurements were measured mostly statically or concentrically by a hand dynamometer and may lack specificity for climbing. During sport climbing and training for climbing, the finger flexor musculature is instead loaded isometrically and to a certain extent eccentrically [16,18]. The aim of this study was to measure eccentric and concentric maximum strength of this musculature using an isokinetic device in order to explore the relationship between eccentric maximum strength and climbing level. The fact that there is a known correlation between isokinetic and isometric maximum strength [11,14] allowed us to assume a connection between those strength qualities in climbers as well.

So far only few isokinetic finger strength measurements [4] and exercise studies have been performed [19]. Three different movements of the forearm musculature (Fig. 1) are investigated and compared: 1.

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eccentric and concentric wrist flexion. 2. eccentric and concentric rolling-in-a-bar with flexion of DIP (distal interphalangeal), PIP (proximal interphalangeal) and MP (metacarpophalangeal) joints. 3. PIP joint flexion. The third out of the three movements is considered to be the most specific climbing task as it simulates the so called crimp grip position [16,18].

2. Material and methods

2.1. Subjects

Fifty hands of 25 male subjects with average age of 32.2 ± 7.7 years (range 16.7–44.9) took part in the study. Exclusion criteria were acute or chronic injuries in one or both sides of the wrists or fingers. All subjects were active rock climbers and have been climbing on average for 11.4 ± 6.3 years (range 2–30). Average body weight was 71 ± 8.5 kg (range 58–93) and average body height of 178 ± 5.2 cm (range 168–189 cm). All participants gave an informed consent.

Concerning sport climbing performance, the most difficult route in on sight and red point style of the last year was recorded. Red point style (rp) is defined by climbing a known route of about 15 to 25 m height. The route has to be climbed from the bottom to the top without technical aid or resting at an artificial point like a bolt. The grade of difficulty is usually so high that a successful ascent is not possible during the first try. The climber trains the route or the difficult sections several times, months or even years until he succeeds. On sight style (os) means climbing an unknown route. The climber is not allowed to watch somebody else climbing the route or obtain information about the route. Difficulty grading was according to the French grading (F) system ranging from 3–9a F with subdivisions such as 3, 4, 5a, 5b, 5c, 6a, 6a+, 6b, 6b+, 6c, 6c+, 7a, 7a+ F etc. This scale is the most often used in Europe and has the fewest subdivisions. The scale is a subjective classification of the difficulty of a climbing route and is not linear. Each French grade F was assigned a numeric value from 1 to 24 for calculating the differences and their statistical significance. Performance of on sight style was on average F 7a+ (range F 6b+ – F 7c) and for red point style F 7b+ (range F 7a – F 8b+). According to the numeric scale it was 12.6 ± 2.7 (range 9-16) for on sight style and 15.3 ± 3.3 (range 12–21) for red point style. The participants climb 8.7 ± 3.6 hours/week (range 3–16).

2.2. Isokinetic movement device

The custom isokinetic movement device (Fig. 1) consisted of a 70x50x55 cm frame that held the motor/gear box unit and the electronic control system as described by Schweizer (2003). Three different frame-like boxes were built which could be coupled to the device unit. Each of the boxes allowed one of the specific movements, wrist flexion, rolling a bar in and out, and isolated flexion in the PIP joint. The movement boxes were connected to the device unit by a cable wire to which a force transducer was attached. A Zuerrer TFVB9-55/2 three-phase electric cage motor (630 Watt) coupled to a worm gear (Zuerrer 2/1MH) with an output torque of at least 30 Nm maintained constant speed during measurements. The speed of the device unit was controlled by a frequency converter (Hardmeier control VF61M R722). Force transmission from the device unit to the movement device box occurred through a tie-rod providing a sinus-like oscillation. This movement pattern was chosen for safety reasons (no uncontrolled increase of range of motion was possible). Furthermore, a forced sinusoidal movement (desmodrom) is much easier to perform than a truly isokinetic movement where the velocity remains strictly constant making a change of the direction of movement more difficult [7].

The first movement box (Fig. 1) allowed the measurement of eccentric and concentric flexion moment of the wrist. A comfortable anatomically shaped handle which could be grasped firmly allowed maximum force transmission from the flexors of the fingers and wrist to the movement device. The handle was in 20° ulnar deviation so that the axle of the device was parallel to the plane of the articular surface of the distal radius. The dorsum of the forearm was placed on a board that acted as a counter-arm against flexion movement. Range of motion was 30° extension and 30° flexion.

The second movement box (Fig. 1) allowed the measurement of eccentric and concentric force of a "rolling in and out" a bar with all fingers (except the thumb). The free turning bar was mounted on a gliding sled on the inner side of the box. An anatomically shaped handle which was grasped by the thumb and thenar acted as a resistance bearing against the flexion movement. The movement in the fingers started by flexion of the distal interphalangeal (DIP) and the proximal interphalangeal (PIP) joints almost continuously until they were in contact with the bar. Slight flexion of the metacarpophalangeal (MCP) joints finished the rolling movement. Linear range of motion of the bar was 40 mm.

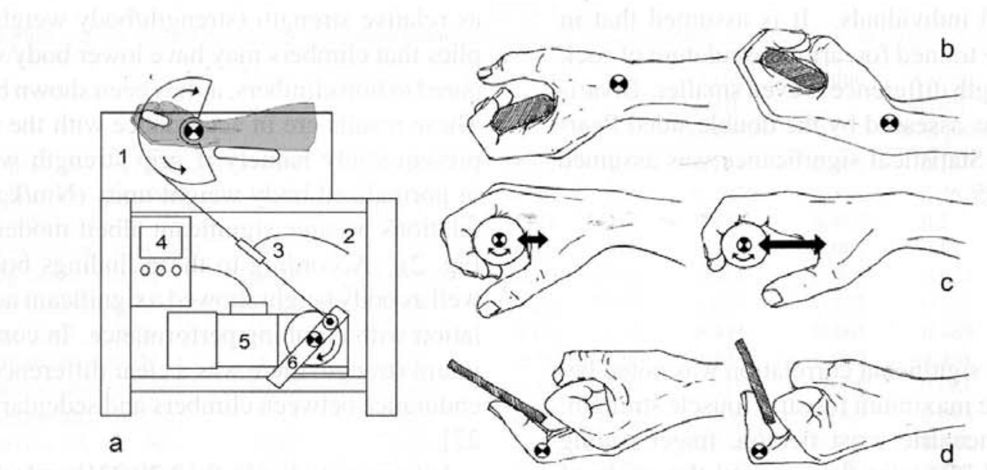

Fig. 1. Isokinetic movement apparatus (a) existing of a frame where the electric drive (5), power supply (4) and one of the 3 movement devices (1) is mounted. A flexible steel cable with a piezoelectric force transducer (3) is connected to the drive (6) allowing an almost sinusoidal reciprocating motion in the movement device. Real time measurement is performed by means of an oscilloscope and a PC (2). Wrist flexion device (b) allowed eccentric and concentric flexion of the wrist of 30° on each side. Device for "rolling in and out a bar" movement (b) allowed eccentric and movement with all fingers (except the thumb) with a range of motion of the interphalangeal joints up to 40° flexion. The PIP joint flexion device (c) allowed only isolated eccentric and concentric flexion of the PIP joint of the middle and ring finger. The external force acted as a rotational movement at the tip of the third and fourth fingers forcing the DIP joint into hyperextension. Range of motion in the PIP joint was between 60 and 100° flexion.

This movement was designed to allow some movement in the interphalangeal joints (flexion up to 40°).

The third movement box (Fig. 1) allowed the measurement of only isolated eccentric and concentric flexion moment of the PIP joint. The wrist was fixed in a splint in 25° extension, the MCP joint in 30° flexion. The external force acted as a rotational movement at the tip of the third and fourth fingers forcing the DIP joint into hyperextension. Range of motion in the PIP joint was between 60° and 100° flexion. For the measurement, the middle and the ring finger were loaded together.

A piezoelectric force transducer (Kistler 9301A SN488642) was connected in series with the cable wires between the device unit and the movement device. The signal was reinforced by a charge amplifier (Kistler Type 5011) and stored by a personal computer supported storage oscilloscope (Voltcraft PCS64i). The accuracy (smallest measuring unit) of the oscilloscope was 0.2 Nm/step for wrist flexion, 5 N/step for finger rolling in and out 0.1 Nm/step for PIP flexion.

The accuracy of the reproducibility of the measurement results by this device has been shown by serial measurements and had a SD of 7% [18].

2.3. *Measurements*

All tests were conducted bilaterally. To develop maximum force in a movement using an isokinetic device requires adequate co-ordination. Before each measurement, every subject was allowed to adapt to the sinusoid movement of the engine as long as he wished and until he felt confident with the device. This precaution was taken to prevent injuries and to be sure that the subject applied reliable maximum force. An eccentric movement influences the maximum force of the following concentric movement positively [3] by an elastic recoil mechanism of the muscle. In order to exclude such influences a relatively low speed of movement was chosen (4 sec./one complete cycle of concentric and eccentric movement) and the subject was instructed to relieve activity shortly in between the concentric and eccentric movement. At least 3 consecutive cycles (usually 4 to 5) of eccentric and concentric movement had to be performed. Frequency of a whole eccentric and concentric cycle was 0.5 Hz for each of the three different devices. The measurements were performed in the following order: 1. wrist flexion, 2. rolling in a bar movement, 3. PIP joint flexion of the left and right hand. There was at least 30 min. pause between each exercise in order to exclude a fatigue effect.

2.4. *Data analysis*

The value of the highest peaks of eccentric and concentric peaks of the left and right side were chosen for evaluation. N.E. Motzkin et al. [13] showed a correlation between the dominant and non-dominant extremity in non trained individuals. It is assumed that in the symmetrically trained forearm musculature of rock climbers the strength difference is even smaller. Bivariate correlation was assessed by the double sided Pearson Test (SPSS). Statistical significance was assumed when it was <0.05.

3. Results

No statistically significant correlation was noted between the absolute maximum forearm muscle strength: eccentric and concentric wrist flexion, finger rolling in movement and PIP joint flexion, and the grade of climbing difficulty (Table 1). Only wrist flexion appeared to be associated with climbing level (rp) although marginally significant ($p = 0.066$). However significant correlations were indicated between the bodyweight normalized strength of all three movements (Table 1) and the climbing level red point and on sight, except for PIP flexion (con- and eccentric). Concentric wrist flexion showed the most distinct correlation ($r = 0.57$, $p < 0.001$) as shown in Fig. 2. There was no bilateral t difference with respect to any of the movements.

There was a negative correlation between body weight and climbing difficulty for both red point ($r = -0.467$, $p < 0.001$) and on sight style ($r = -0.477$, $p < 0.001$. There was also a weak relation between body height and climbing difficulty in which smaller climber performed better ($r = -0.379$, $p = 0.007$; $r = -0.406$, $p = 0.003$).

4. Discussion

Maximum strength of the finger flexors in rock climbers has been investigated differently and was reviewed by Giles [6] and Watts [21]. The results concerning differences of maximum strength compared to sedentary subjects were contradictory. While Grant [9] claimed that climbers have greater grip strength than non climbers (532 N SD 23 vs. 478 N SD 23) Mermier [12] found no differences between those two groups. In contrast Iriberri [10] used climbing specific tasks and showed a correlation of strength with climbing performance in high level climbers. The ten climbers, however, had very similar body weight (mean: 64.54 kg, SD 4.59). Watts [23] found no difference of maximum grip strength between climbers and non climbers. The differences however were significant when expressed as relative strength (strength/body weight). This implies that climbers may have lower body weights compared to non climbers, as has been shown by Watts [23]. These results are in accordance with the results of the present study namely if grip strength was expressed in normalized body weight units (Nm/kgbw) the correlations became significant albeit moderate (Table 1, Fig. 2). According to these findings body weight as well as body height showed a significant negative correlation with climbing performance. In contrast to maximum strength there was a clear difference of handgrip endurance between climbers and sedentary subjects [5, 22].

In former studies [8,9,12,20,23] hand related strength measurements were performed mostly with a handgrip dynamometer. This device measures a static – concentric muscular performance which may not be applicable to climbing related strength [6] where load to the finger flexors is rather static or eccentric. At the moment when a climber is getting a grip, body weight is acting as the resistance and pulls the finger flexors in an eccentric direction until they are in their final position. Notably during the so called crimp grip position [16] the finger flexors engage to the flexor tendon pulleys to develop a considerable amount of friction consisting of almost 10% of the holding force [18]. It has been shown that the difference between the eccentric and concentric maximum strength of the finger flexors is considerably higher (30%) compared to other forearm muscle movements, such as wrist flexion (15%), and was assumed to be due to friction [18]. The crimp grip movement in this study, the most specific grip for sport climbing, was assumed to show a high correlation with climbing performance. The results showed however, that the least specific climbing movement, concentric wrist flexion maximum strength, had the highest correlation of all investigated movements with climbing performance for on sight and redpoint style. One of the reasons why the PIP joint flexion movement did not correlate best with climbing performance, may be its complicated, challenging and harmful task. The movement loads only the third and fourth finger leaving the small in completely flexed position. This pulls the two origins (at the FDP of the ring and the small finger) of the fourth lumbrical considerably apart and may lead to a muscle tear, a typical climbing injury [17]. Besides that, the PIP flexion movement causes maximum load to the A2, A3 and A4 pulleys, which in turn may harm these structures, which is one of the most often and specific climbing injury [1,15,16]. This may had an influence that participants have been too reluctant for

Table 1
Absolute (abs.) and relative (rel.) maximum strength (eccentric and concentric) of the three investigated movements

	Mean	maximum	minimum	SD	Correl. coeff. On sight	p-value	Correl. coeff. Red point	p-value
Wrist flex. abs. ecc. Nm	23.08	36.20	16.00	4.58	0.121	0.401	0.187	0.192
Wrist flex. abs. con. Nm	19.46	31.60	13.40	3.68	0.207	0.149	0.262	0.066
Wrist flexion rel. ecc. Nm	0.32	0.44	0.21	0.06	**0.431**	**0.002**	**0.5**	**<0.001**
Wrist flexion rel. con. Nm	0.27	0.39	0.16	0.05	**0.515**	**<0.001**	**0.57**	**<0.001**
Rolling in abs. ecc. N	596.70	800.00	410.00	97.58	0.011	0.941	0.034	0.813
Rolling in abs.con. N	441.20	575.00	285.00	77.43	0.087	0.548	0.133	0.356
Rolling in rel. ecc. N	8.39	11.80	5.69	1.18	**0.441**	**0.001**	**0.468**	**0.001**
Rolling in rel. con. N	6.22	9.03	4.58	1.07	**0.43**	**0.002**	**0.481**	**<0.001**
PIP flexion abs. ecc. Nm	10.53	16.80	5.40	2.79	0.017	0.905	0.061	0.673
PIP flexion abs. con. Nm	7.48	11.60	4.10	2.02	0.006	0.967	0.093	0.52
PIP flexion rel. ecc. Nm	0.15	0.25	0.09	0.04	0.226	0.114	**0.312**	**0.028**
PIP flexion rel. con. Nm	0.11	0.17	0.06	0.03	0.215	0.134	**0.319**	**0.024**

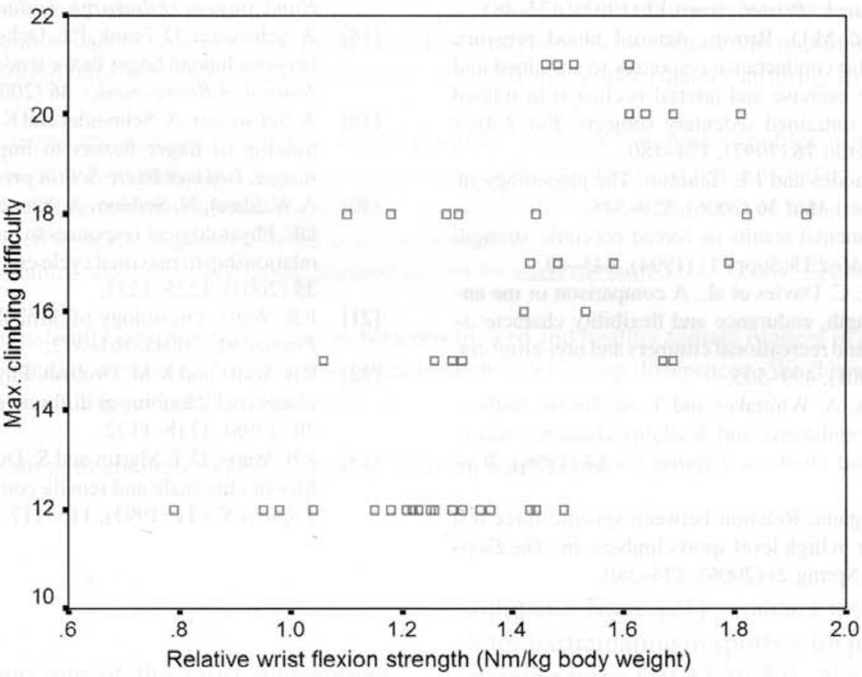

Fig. 2. Correlation of relative concentric wrist flexion strength in Nm / kg body weight and climbing performance.

a maximum effort compared to the more simple wrist flexion task. Wrist flexion, in turn, is a daily performed common movement which does not lead to such muscle ineterferences. There is also no such high redirection of force by the flexor tendons at the flexor retinaculum of the wrist joint. There again a considerable part of the muscles which flex the wrist are the same muscles to flex the fingers. The moment arms of all four FDS (flexor digitorum superficialis) and FDP (flexor digitorum profundus) muscles at the wrist are around 1.5 cm which approximates the 1.8 cm of strongest wrist flexors, the FCR (flexor carpi radialis) and the FCU (flexor carpi ulnaris) [2]. The flexion moment at the wrist of all finger flexors (FDS and FDP) comprise 58% of the whole flexion moment whereas the FCR and the FCU together comprise the remaining 42% which can be calculated by the data from Brand and Hollister [2]. The finger flexion strength therefore has a considerable influence on the wrist strength which in turn may explain the correlation with climbing performance in this study. Concerning specificity of the movement and results the rolling in a bar movement is positioned in between the two above mentioned movements. Due to the construction of the device (Fig. 1b) the whole 4 finger flexion force must be resisted by the thenar eminence and the thumb. Weakness, pressure pain or handle discomfort may avoid the full finger flexion strength development and may have influenced results negatively.

Within the forearm musculature, concentric wrist flexion may be considered as the best predictor for climbing performance and may be, due to its ease of application, valuable as a performance test for rock climbers.

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