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Effect of simulated rock climbing finger postures on force sharing among the fingers

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Abstract

Objective. To study the forces applied by each finger in different joint postures simulating rock climbing gripping postures.

Design. Subjects in sitting posture applied fingertip forces perpendicular to horizontal force sensors in three different finger postures.

Background. Data provided by the literature indicate that middle and ring finger are commonly injured. However, no quantitative assessment of the forces applied by each finger related to the joint postures has been made.

Methods. Six elite rock climbers performed finger flexion in a single-finger task and a four-finger task. The tests were conducted in an extended posture, a curved posture (the joints belonging to the finger were flexed) and an intermediate posture (the joints were flexed, except the distal one which was fully extended). Each fingertip force was expressed in absolute value and in percentage of the maximal force capacity of the finger.

Results. The greater force was applied by the middle finger (20.8 N), whatever the posture. The relative involvement amounted to 105% for the ring finger in the curved posture.

Conclusions. The great force applied by the middle finger and the great relative involvement of the ring finger in the curved posture seem to be the main factors of injuries of these fingers.

Relevance

The analysis of force sharing among the fingers during different joint postures mimicking rock climbing is essential to a better understanding of finger injuries.

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Keywords: Rock climbing; Force sharing; Fingertip force

1. Introduction

There has been remarkable development in the scope and quality of rock climbing during the last couple of years. In this activity, the hands are used as tools for the ascent and many of the external forces applied upon the fingers are distributed through the wrist, elbow and shoulder (Hass and Meyers, 1995; Quaine et al., 1997). Three quarters of elite and recreational sport climbers suffer from injuries at the upper extremities (Rooks, 1997). Sixty percent of these injuries involve the hand

and 40% of elite climbers have signs of failure to the A2 pulley (Bollen and Gunson, 1990). Failure to the A2 pulley arises when the flexor tendon sheaths are overloaded. This often occurs when the climber moves either to or from a small hold. Failure is largely acquired as a function of the grip techniques, the middle and ring fingers being most commonly injured (Schweizer, 2001). The pathomechanics of the rupture of flexor tendon pulleys is well described on cadaveric fingers (Sharkey et al., 1998) but is unknown during climbing, since no study has analyzed the forces applied by the fingers. We hypothesized that the middle and ring fingers are commonly damaged because they apply greater fingertip forces. The purpose of this study was to examine the forces applied by each finger in various simulated postures used in rock climbing.

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2. Methods

Six elite males rock climbers participated in the study [age: 22 (SD 1.4) years; height: 177.4 (SD 4.5) cm; body mass: 65.6 (SD 2) kg; hand length from the middle fingertip to the distal crease of the wrist with the hand extended: 19 (SD 1.5) cm]. All subjects have been practising for ten years on average (five times per week). They signed an informed consent in accordance to the University guideline.

2.1. Apparatus

Since a previous work (Quaine et al., 1997) shows that high postural constraints associated to postural balance in rock climbing induce significant intra and intersubject supporting force variability, the subjects sat on a chair. In this case, the postural constraints are insignificant and it was easy to control and modify the grip posture for each subject. A device (Fig. 1) was assembled in the global reference system (O, x, y). A vice was used to stabilize the upper arm. A clamp was used to stabilize the palm of the hand. The wrist was positioned at 40° of extension. The upper arm was at 45° of abduction, the elbow joint being flexed at 90° . A digital camera (Sony, DSC-S70) located 0.70 m above the device was used to control the finger posture. It measured the sagittal Index finger posture. Two markers per segment were used. The markers were aligned with the longitudinal axis of the segment. The angle of intersection of the lines of adjacent segments defined the joint angles. The angles were assumed to be similar for the four fingers. An extended finger displayed 180° joint angles.

Four parallel mono-axial load cells (Schlumberger, model CD-750, Vélizy Villacoublay cedex France) were used for vertical force measurement (see (Valero-Cuevas et al., 2000) for details). Steel plates (20 mm \times 15 mm) were fastened to the four load cells, providing finger contact areas. The space between the plates was 4 mm. The pitch between the fingers was 19 mm. The thumb did not act against any support as an additional gripping force.

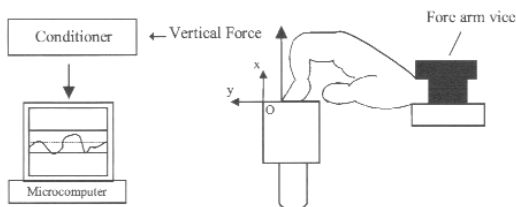


Fig. 1. Experimental setup. The posture corresponds to the 'crimp' posture in the text.

2.2. Data processing

Subjects warmed up on the device by carrying out a series of one hundred contractions for 5 s at 10 N (Schweizer, 2001). They were then asked to press the force sensors at maximal intensity with the index (*I*), middle (*M*), ring (*R*) and little (*L*) finger separately and then the combination IMRL. Subjects were asked to perform fingertip forces in the vertical direction as requested by previous authors (Zatsiorsky et al., 1998).

Three trials for 8 s were required for each task. A 2 min resting period was allowed after each trial in order to avoid fatigue. The highest peak force generated during each trial was adopted as maximal voluntary contraction force (MVC).

The tests were conducted in three different finger postures (Fig. 2): The first posture was labeled REF in the text. It consisted in maintaining both distal and proximal interphalangeal joints (DIP and PIP) straight, and metacarpophalangeal joint (MCP) with 140° of flexion (Zatsiorsky et al., 1998; Li et al., 1998; Danion et al., 2000). The second posture corresponded to the climber's 'crimp' posture (labeled CRI) and was characterized by the hyperextension at DIP (210°), and 100° and 160° of flexion at PIP and MCP. The third posture was the climber's 'slope' posture (labeled SLO), where DIP, PIP and MCP were flexed at 150° , 160° and 150° respectively. These postures have been described previously and the angles are frequently used during climbing (Schweizer, 2001).

2.3. Calculated parameters

Single-fingertip force. It is the maximal force generated by a finger in the single-finger task: F_i with $i = I, M, R$ and L .

Four-fingertip force. It is the maximal force produced by an individual finger in the four-finger task: F_i^{IMRL} with $i = I, M, R$ and L .

The resultant four-fingertip force was calculated as: $F_{\text{max}}^{\text{IMRL}} = \sum_i F_i^{\text{IMRL}}$ with $i = I, M, R$ and L .

Relative involvement of each finger. It was defined as the percentage of maximal force produced by an indi-

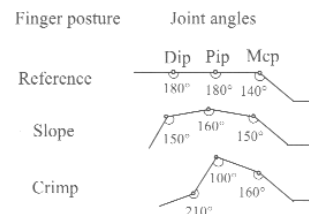


Fig. 2. Simulated finger postures. Dip and Pip correspond to the distal and proximal interphalangeal joints. Mcp corresponds to the metacarpophalangeal joint.

vidual finger in the four-finger task compared with the maximal force generated by the same finger in the single-finger task as: $C_i = (F_i^{IMRL}/F_i) \times 100\%$ where i represents the involved finger in the task.

2.4. Statistical analysis

Descriptive statistics are means and standard deviations. A one-factor ANOVA (*Posture*) with repeated measures was used to analyze the differences in resultant external force. Two-factor ANOVAs with repeated measures (3×4 , *Posture* \times *Finger*) were used to analyze the force applied by each finger during the single and four-fingertip tasks in the different postures. A level of $P < 0.05$ was considered to be statistically significant.

3. Results

Single-fingertip force F_i : Maximal forces for individual fingers in single-finger task are shown in Table 1. The ANOVA indicates a significant effect of *Finger* ($F(3, 15) = 14.6, P < 0.00004$). The maximal forces of the index and the middle finger were not statistically different and were greater than those of the ring and little finger. The force of the ring finger was not statistically different from the force of the little finger. No significant effect was observed for *Posture*, nor for the interaction *Posture* \times *Finger*.

Resultant four-fingertip force F_{max}^{IMRL} : The magnitude of the force is represented in Fig. 3. No significant difference was observed between the external force magnitudes performed in each posture. In REF, the mean force amounted to 58.6 (SD 21) N. In CRI and SLO, it amounted to 61.4 (SD 25) N and 65.9 (SD 14) N respectively.

Four-fingertip force F_i^{IMRL} : The contribution of each finger to the resultant force is presented on Fig. 4. The ANOVA results show no significant effect of *Posture*. The mean external force magnitude was the same for each climber's grip, whatever the finger. A significant effect of *Finger* was observed ($F(3, 15) = 22.64, P < 0.00008$). The mean external force magnitude was different for each finger, whatever the posture. Newman-Keuls post-hoc analysis among all the possible pairs of the four fingers shows that the force applied by the index was not statistically different from the one applied by the middle

Table 1
Mean (SD) single-fingertip force (N) at the index (*I*), middle (*M*), ring (*R*) and Little (*L*) finger in the climber's "reference" (REF), "crimp" (CRI) and "slope" (SLO) postures ($n = 6$)

Postures	<i>I</i>	<i>M</i>	<i>R</i>	<i>L</i>
REF	34.7 (8.6)	33.2 (9.5)	18 (6.7)	11 (3.9)
CRI	21.5 (7.3)	20.7 (6.3)	15.1 (6.3)	15.2 (2.8)
SLO	22.8 (8.5)	23.5 (8.4)	11.9 (5.7)	16.7 (3.7)

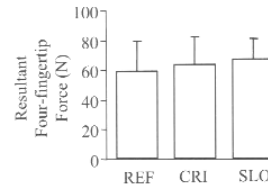


Fig. 3. Resultant four-fingertip force (F_{max}^{IMRL}) in the climber's "reference" (REF), "crimp" (CRI) and "slope" (SLO) postures. Error bars indicate standard deviation.

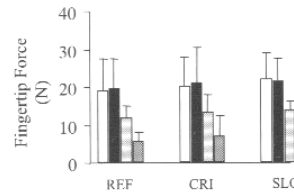


Fig. 4. Four-fingertip force (F_i^{IMRL}) applied beneath each finger (□) index; (■) middle; (▒) ring; (■) little). Error bars indicate standard deviation. REF is the climber's "reference" posture, CRI the "crimp" posture and SLO the "slope" posture.

finger. They amounted to 20.5 (SD 7.33) N and 20.8 (SD 7.6) N respectively. They were statistically greater ($P < 0.05$) than the forces applied by the ring finger [13.1 (SD 3.4) N] and by the little finger [7.14 (SD 3.6) N]. The interaction *Posture* \times *Finger* showed no significant effect. This means that the external force magnitude increases similarly for each finger in the climber's "reference", "slope" and "crimp" postures.

Relative finger involvement C_i : In the IMRL task, a significant *Finger* effect was observed ($F(3, 15) = 15.87; P < 0.0001$), while no effect was observed for *Posture*. The interaction *Posture* \times *Finger* (Fig. 5) was significant ($F(6, 30) = 2.6; P < 0.03$). Post-hoc analysis indicates that the climber's posture led to a drop in the relative finger involvement only for the middle [93 (SD 21) %] and the ring [105 (SD 28) %] fingers in the "slope" posture ($P < 0.05$). There was no significant change

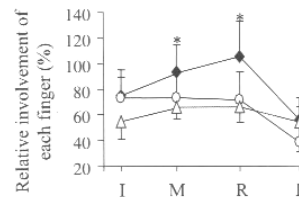


Fig. 5. Relative involvement of each finger (C_i) for the index, middle, ring and little fingers (*I*, *M*, *R* and *L*) during the "slope" (◆); "crimp" (○) and "reference" (△) postures. Error bars indicate standard deviation. * indicates a significant difference between the relative involvement values for the middle and ring fingers and all others values ($P < 0.05$).

concerning all the other values. They fluctuated between 38 (SD 28) % and 75 (SD 20) %.

4. Discussion

Our results show that the “crimp” and the “slope” posture do not affect the resultant force magnitude. This is conflicting with a previous report (Cutts and Bollen, 1993) which showed that the external force was greater during the climber’s “crimp” posture than during the “slope” posture. However, the handgrip dynamometry presented in this study (Cutts and Bollen, 1993) involves an isometric contraction of the fingers in opposition to the thumb and the base of the hand, whereas the present study requires a different involvement of the fingers. The extended finger posture allows direct comparison with data in the literature (Li et al., 1998; Danion et al., 2000) and shows that the relative force distribution among the fingers is replicated in the present experiment. This means that rock climbers behave similarly to non-climber subjects (previously tested) when the external force is produced by all the fingers in an extended posture.

Moreover, the present results confirm that the fingers are not equally involved in the resultant force production. The greater involvement concerns the middle finger, followed by the index, the ring and then the little finger in each posture. This result validates a part only of our hypothesis: the most frequent middle finger injuries may occur because this finger applies the greater forces. Nevertheless, the explanation concerning the ring finger is less explicit. As previously mentioned (Li et al., 1998), this finger applies reduced force in single-finger task, but the necessity to minimize unnecessary rotational moment with respect to the functional longitudinal axis of the hand (Li et al., 1998) induces a great appeal on force production for this finger. This explains the high percentage of relative force in four-fingertip task and may explain the ring finger injuries in rock climbing.

5. Conclusions

The results show that the simulated climber’s finger postures induce different force distributions among the four fingers when they act simultaneously. The most significant forces are always applied by the middle and index finger, followed by forces applied by the ring then by the little finger, which may explain the middle finger injuries. Furthermore, the relevant factor of injury for the ring finger in rock climbing seems to be the most significant relative force applied by this finger, particularly in the slope posture.

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