Effect of the grip position on maximal fingertip force during a rock climbing gripping exercise

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Abstract

This study shows how the force distributes between the fingers with different grip positions and whether there is a connection between force distribution and climbing ability. 20 male and 6 female climbers of various climbing abilities volunteered for the study. We built a separated artificial climbing grip like a ledge where each element of the width of one finger measures the holding force of a finger. Our study showed significant differences in force production among individual fingers in various grip techniques in climbing. The results show that the little finger plays a more important role in higher climbing and bouldering performance level. So performance-oriented climbers could benefit from focusing on this finger in both physical and coordinative training aspects.

Keywords: Climbing, Bouldering, Finger-strength, Training, Performance, Coaching

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1 Introduction

Climbing has been part of the Olympic Games since 2020. Interest in research into optimal grip technology and maximizing finger strength is growing. Many studies have shown that relative finger strength respective finger endurance is one of the most important physiological factors for climbing performance [1, 2, 3, 4, 5]. However, the procedures for measuring finger strength differ in used methods and devices and make it difficult to compare results. Regarding finger strength some of them use hand grip dynamometers [1, 6, 7] others use ledges with a climbing-specific grip depth combined with a scale [8]. To find out interrelationships among different grip techniques, joint angels and force vectors also “self-made devices” already were used [9, 10, 11, 12]. Only a few studies so far used devices which were able to display forces on every single finger during different climbing grip positions [9, 11] and distinguish between different climbing sub disciplines like bouldering and rope climbing [13].

The type of grips and the individual finger strength can make the decisive difference in a competition. A targeted training to intensify the individual finger forces and at the same time a quantitative measurement of the training success would be desirable. For narrow holds, climbers use various types of crimps, closed and open ones [14, 15, 16]. The difference between the crimps lies in the maximum flexion in the proximal interphalangeal joint (PIP) and hyperextension in the distal interphalangeal joint (DIP) [17]. The crimp is not only the first point of contact with the wall, but also the first stabilizing link in the climber’s chain. The goal here is to establish the most positive connection possible, which ensures that the body can build up stabilizing torques as a result. If this is done, a climbing movement can be performed or even a resting position can be achieved [9, 11]. This study analyzes the force distribution in the fingers is applied with different grip positions and analyze the connection force distribution and climbing ability.

2 Methods

2.1 Participants

20 male and 6 female climbers of various climbing abilities volunteered for the study. The average age of the male/female participants were 32/31, the size 179/166 cm and the body mass 72/56 kg. 23 subjects were right-handed, 3 left-handed and one reported ambidexterity. To classify climbing difficulty between participants we used the French numerical grade system as it is an international applied system and the only one in which you can display boulder (Fontainebleau fb scale) and climbing difficulty (French sport scale) in the same grade system [18]. It has 9 degrees and inter-grades “a“ to “c” as well as plus and minus. The climbers reported their climbing abilities between 6b and 9a in rope climbing and 6b and 8b bouldering on the fb scale during their career and also in the last 12 months. For more informations see table 1 and table 2 in appendix.

2.2 Measuring device

This device consisted of a separated artificial climbing grip like a ledge of a depth of 22 mm where each element of the width of one finger (17 mm) was able to measure the holding force of only this finger. The gaps between the keys were 1mm wide. The ledge was equipped with strain gauges which were sampled at 10 Hz and recorded by a custom software in python and html. The processing hardware equipment consisted of an amplifier board with integrated and calibrated A/D converter (HX711). The signal is processed by a system on chip microcontroller with integrated WI-FI (ESP32). Data is sent to a laptop by WI-FI in real-time for display, analysis and permanent recording. Wooden keys (arranged like a keyboard; Figure 1) were rigidly connected to the transducers.

Figure 1: The structure with variable height adjustment for the force measuring device to guarantee optimal shoulder centering is shown in the left part of the figure. The body can be braced against the device with the help of a bar above the upper legs. In the right part of the figure the finger positions are shown. From top to bottom half crimp with four fingers (HC4), slope handgrip with four fingers (SG4) and slope handgrip with three fingers (SG3).

2.3 Measuring principle

During the measurements, the participants' height, weight, ape index, possible injuries and the time of the last training session were recorded. The measurement device was mounted to a wooden device above a chair so that the height could be adjusted according to the arm length of the participants.

To maintain a high validity in assessing finger strength for climbing we used a test setup in accordance to Balas et al. [8]. The shoulder was flexed at 180° and elbow fully extended. In order to enable maximum force generation in fingers as one end of chain and high criterion validity, we tolerated a flexion of maximum 10° in the elbow joint during measurement. Participants do the exercises while seated, with a bar preventing them from pulling their bodies up. (see Figure 1).

The exercises were done under the supervision of an experienced climber to avoid touching the thumb on the sides of the measuring device and to ensure the proper execution of the exercises. Each climber was measured before training and did not exercise excessively the day before. Before the measurement, a warm-up program was carried out and then paused for 5 minutes. The finger positions, which were measured twice during the measurement, were explained to the participant and held constant during all trials. There was a 5-minute break between each finger position. The participants were encouraged to use chalk. The climbing grip was cleaned after each exercise and the temperature in the room kept constant. Three grip positions were defined in accordance to Amca et al. [12] and measured:

1. half crimp with four fingers (HC4)
2. slope handgrip with four fingers (SG4) and
3. slope handgrip with three fingers (SG3) (Figure 1 top HC4, middle SG4, bottom SG3).

All of these grips are common grip position in climbing [18], whereby SG3 is rarely seen in studies. A full crimp position has not been tested in order to avoid injuries [10] and incorrect measurements by the thumb on the index finger key. For every participant the left and right hand was tested and recorded.

2.4 Data Analysis and Statistics

To remove measurement noise from the data, raw data is first filtered with a window of three measured values. The measured data of the individual fingers is added up to a total finger force over time. The individual finger forces were then normalized with the maximum total finger force. In the following, "relative force" is used to denote the maximum value of the total finger force. The difference between two data sets was tested for significance with the t-test, with a confidence level of at least 95% being assumed and effect sizes are given according to Cohen's D.

3 Results

The total finger force of the climbers was 361.91 ± 12.35 N left hand and 288.14 ± 54.15 N for the right hand of the female and 570.51 ± 87.37 N left hand and 560.82 ± 77.90 N for the right hand of the male. The t-test (left hand $t = -9.57$, $P < 0.001$, Cohen's $D = 2.33$ and right hand $t = -8.97$, $P < 0.001$, Cohen's $D = 2.38$) showed that the forces exerted by the female climbers were significantly lower than that exerted by the male climbers.

The mean relative force per finger for all subjects is shown for the various grip positions in Figure 2. The average relative finger force of all positions from high to low therefore results to:

- HC4: $I \geq M > R > L$ for left and $I \geq M \geq R \geq L$ right hand
- SG4: $M > I > R \geq L$ for left and $M \geq R \geq I = L$ for right hand
- SG3: $R > I = M$ for left and $R > M = I$ for right hand

where I,M,R and L stands for index, middle, ring and little finger and '$>$' indicates a significant difference ($P<0.001$), '$\geq$' indicates a significant difference ($P>0.001$ and $P<0.05$) and '$=$' indicates a non-significant difference ($P \geq 0.05$).

In the SG3 position, the relative forces of the ring finger are significantly ($P<0.001/0.001$ left/right hand) higher than those of the index ($t=6.04/7.69$, Cohen's $D=1.27/1.59$ left/right hand) and middle fingers ($t=5.74/5.82$, Cohen's $D=1.23/1.26$ left/right hand). In the SG4 position, the relative forces of the middle finger are significantly ($P<0.001/0.05$ left/right hand) higher than those of the index ($t=-4.63/6.05$, Cohen's $D=0.75/1.28$ left/right hand), ring ($t=5.55/2.03$, Cohen's $D=0.92/0.44$ left/right hand) and little finger ($t=6.30/1.11$, Cohen's $D=1.12/1.59$ left/right hand). In the HC4 position, no significant deviations in the forces of individual fingers could be determined.

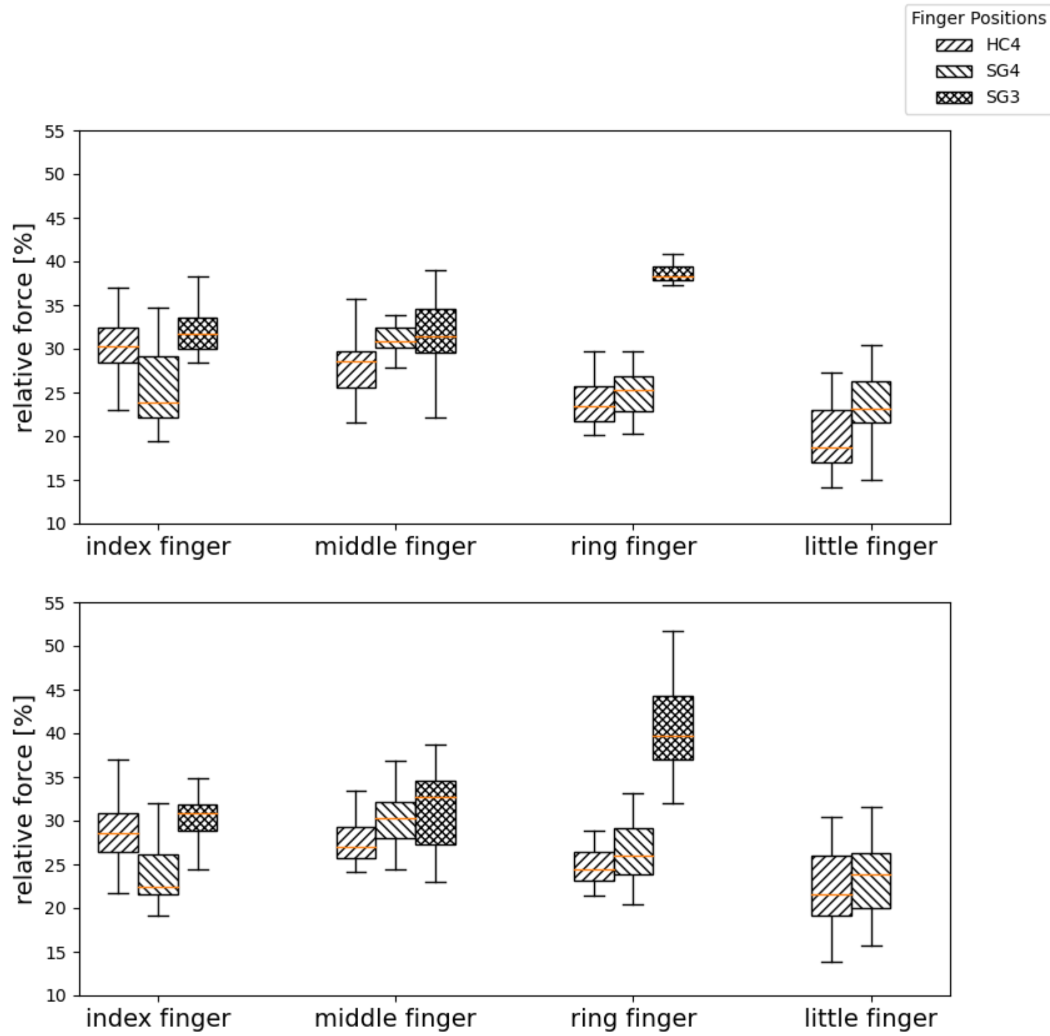

Figure 2: Relative force used for the left hand (top) and the right hand (bottom) for all climbers. The boxes of HC4 are filled with a hatch pattern like '/', SG4 are filled with '\' pattern and SG3 are filled with 'x' hatch pattern.

The measured relative force over time for two male climbers is shown in Figure 3, with some force curves being very different. For the force curve on the left, the force of the index-finger decreases after 35 seconds and is compensated by the little-finger at the same time. In the other force curve, the force of all fingers increases simultaneously.

In order to analyze whether a higher degree of climbing goes hand in hand with higher finger strength, the relative force of the four fingers is shown in color according to the fb-scale in Figure 4. In SG3 and SG4 there is no significant difference between climbers with a high degree (>7c+) than climbers with a low degree (<7c+). In HC4 the significant difference results in:

- low I $\geq$ high I, low M $\geq$ high M, low R $=$ high R, low L $<$ high L for bouldering and
- low I $=$ high I, low M $\geq$ high M, low R $=$ high R, low L $=$ high L for climbing degrees

Where, I, M, R and L stands for index, middle, ring and little finger and '$\geq$' indicates a significant difference ($P>0.001$ and $P<0.05$) and '$=$' indicates a non-significant difference ($P\geq0.05$). Low describes

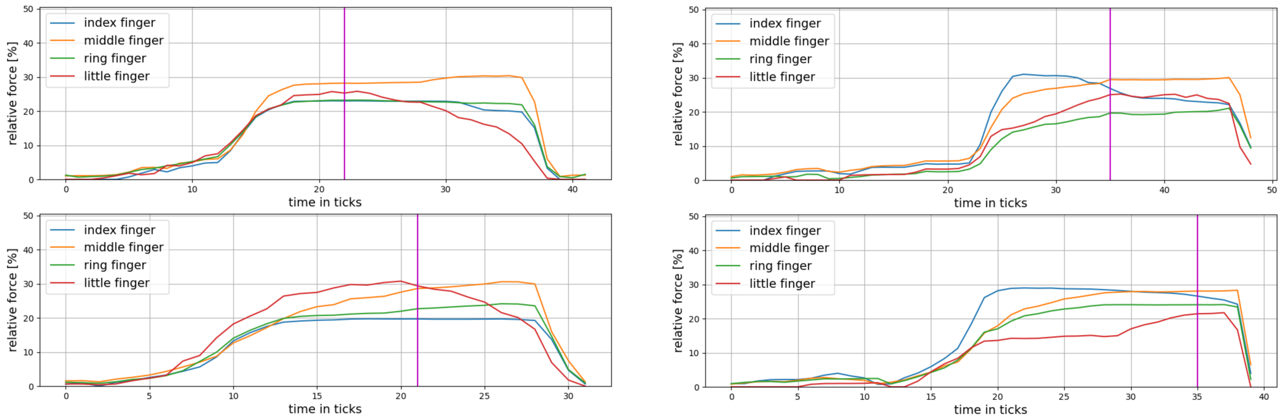

Figure 3: Finger force curve over time for two male climbers (left side and right side). In the top row the forces of the left hand and in the bottom row the forces of the right hand are shown. Magenta indicates the point of the highest force.

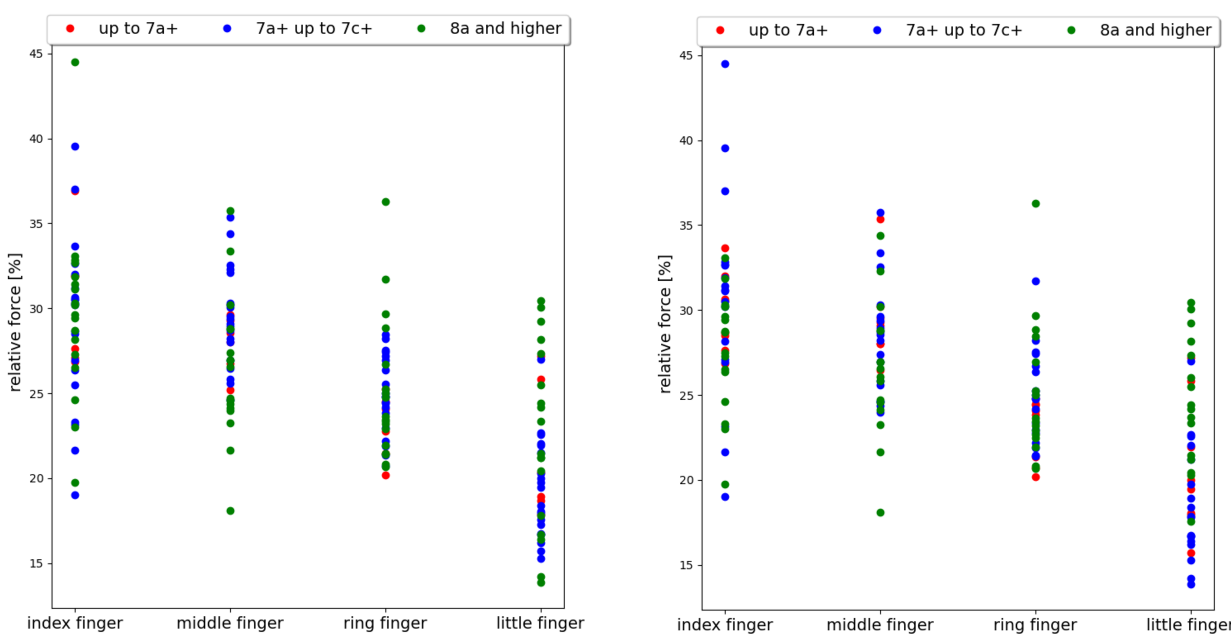

Figure 4: Relative finger force for four fingers (half crimp) is color coded according to the climbing level (left) and bouldering level (right).

the degrees <7c+ and high describes the degrees >7c+. The direction of the larger character describes the larger or smaller mean value of the finger.

From this we conclude that there is a discernible difference between the high boulder degrees for finger strength, such that the middle finger (t=-2.06, Cohen's D=0.5) and index finger (t=-2.09, Cohen's D=0.44) are loaded less and the remaining resulting load is distributed towards the little finger (t=4.78, Cohen's D=1.06). With the climbing grades, there is only a reduction in the relative force on the middle finger. There is no significant increase in the force on the other fingers.

4 Discussion

Due to the different grip positions, test devices and setups it is difficult to discuss results between several studies. The studies from Fuss & Niegl [11] and Vigouroux et al. [19] seemed most similar to ours in terms of used device (force sensors for each finger) and test setup (forearm in a vertical position). Differences still remain in the test setup of these two studies. Fuss & Niegl [11] collected the data during climbing movement with sensors fixed on a climbing wall, whereas Vigouroux et al. [19] like us used a static position with the subject seated, but the elbow resting on a support.

Especially the position of the forearm and the upper arm should be considered to obtain a high criterion validity of the test. In earlier studies using single-finger load cells like Quaine et al. [9] the forearm was in a horizontal position with the wrist fixed in a clamp, which we think in accordance to Fuss & Niegl [11] is not a climbing-specific arm position, however this test setup required a rather controlled environment. A test during climbing on the other hand could have a negative effect on maintaining the exact grip position during measurement, as a change in shoulder position is related with a change in interphalangeal joints, too [20]. We decided to take a compromise between controlled joint positions and criterion validity, following the recommended test setup of Balas et al. [8].

Regarding the grip positions, there are still inconsistent classifications, thus it is necessary to allocate different definitions. Results in this study can be compared with results of Fuss & Niegl [11] and Quaine et al. [9]. HC4 position in our study is defined as "open crimp" and SG4 as "open handgrip" in Fuss & Niegl [11] as well as "slope" in Quaine et al. [9].

Our results for SG4 position ($M > I > R \geq L$, left hand; $M \geq R \geq I = L$, right hand) confirm the results of Fuss & Niegl [11] with highest force production in the middle finger and lowest force production in little finger ($M > I = R > L$, right hand), but differ with both index and ring finger. The reason for the difference between the two studies as well as between the two hands in our study might be related to individual varieties in force distribution among the fingers seen in the force-time diagrams (see Figure 3). We assume that anatomical specificities like differences in finger length and in using degrees of freedom in the joints of the pulling chain are an important factor of explanation.

The results of the HC4 position ($I \geq M > R > L$, left hand; $I \geq M \geq R \geq L$, right hand) differ from those of Fuss & Niegl [11] with $M > I = R > L$ (right hand). Only the higher force production of middle finger compared to ring finger is equal. One explanation could be that the test settings differ too much from each other.

We were also able to get some new data of the SG3 grip position, but we weren't able to find a study to compare results. The highest force production was found in the ring finger ($R > I = M$, left hand; $R > M = I$, right hand), whereas index and middle finger displayed equal forces. This is interesting and maybe can explained with a slight change in joint angels especially in the wrist, when skipping the little finger in order to enable maximum force production. Another interesting result is the significant higher distribution of force to the little finger in the HC4 position in relation to a climbing level as of 8a (Climbing as well as Boulder) and higher. In all mentioned studies with force sensors for each finger [9, 11, 19] the force generated by the little finger is lower than every other finger.

It seems that there is some potential for improvement in grip strength and climbing performance in optimizing the contribution of this finger to overall grip strength. Further research has to show if this is an aspect of increasing physical strength or enhanced coordination or both of it.

5 Conclusion

Our study showed significant differences in force production among single fingers in various grip techniques in climbing. High performance in climbing and bouldering comes along with a high technical ability for body stabilizing and precision during movement. This is related to sophisticated gripping techniques as they remain as one end of the movement chain. Consequently, they play a very important role in stabilizing the body and optimizing the force distribution during climbing. Analyzing the force production of different fingers in various grip positions and design of specific training plans according to a strength-weakness profile could play a more important role in future climbing. Furthermore, there is a coordinative aspect in the ability to slightly change the grip position during movement in order to maintain functional joint positions. The results have shown that the little finger plays a more important role in higher climbing and bouldering performance level. So both performance oriented climbers and their coaches could benefit from focusing on this finger in both physical and coordinative training aspects. As studies show that grip strength is highly (males) or moderately (femals) genetical determined [21, 22], the coordinative aspect of training grip strength maybe is still underestimated.

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7 Appendix

subject	Preferred Hand	Age	Weight	Size	Gender	Past injuries	Climbing ratio (outdoor/indoor)	Favorite grip
1	right	30	63	166	w	yes	50/50	crimps
2	right	21	55	170	w	no	80/20	crimps
3	right	34	54	164	w	yes	30/70	crimps
4	right	44	51	160	w	no	10/90	crimps
5	right	40	63	168	w	no	5/95	crimps
6	right	19	50	170	w	no	90/10	crimps
7	right	35	69	185	m	yes	50/50	pockets
8	right	53	71	171	m	yes	40/60	crimps
9	right	38	59	170	m	yes	97/5	crimps
10	both	26	63	167	m	yes	20/80	crimps
11	right	33	77	178	m	yes	95/5	crimps
12	right	27	66	183	m	no	95/5	crimps
13	left	29	81	190	m	no	70/30	crimps
14	right	33	78	182	m	yes	30/70	jams
15	right	39	70	179	m	yes	50/50	pockets
16	left	21	62	170	m	yes	95/5	crimps
17	right	30	73	180	m	yes	50/50	crimps
18	right	41	75	171	m	no	20/80	crimps
19	left	21	73	180	m	no	70/30	crimps
20	right	20	73	180	m	yes	30/70	crimps
21	right	51	72	182	m	yes	20/80	crimps
22	right	42	75	178	m	yes	95/5	sloper
23	right	28	78	178	m	yes	20/80	crimps
24	right	27	75	187	m	yes	60/40	crimps
25	right	18	73	176	m	no	99/1	crimps
26	right	23	75	191	m	no	5/95	crimps

Table 1: Information about the participants.

Ssubject	highest climbing grade	highest bouldering grade	highest bouldering grade – last 12 months	highest bouldering grade – last 12 months	training experience on fingerboard	climbing experience
1	7b+	7b	7b+	–	yes	20
2	6b+	6b	6b+	6b	no	1
3	7c	7a+	7c	7a	yes	10
4	8a	8a	7c+	7b	no	20
5	7b+	8a	–	7c	yes	17
6	8b	7b	7c	–	yes	8
7	7c	7a	7b+	–	yes	12
8	8c	8b	8a+	8a	yes	42
9	7c+	7c	–	7b	yes	7
10	9a	8b	9a	8a+	yes	15
11	–	7c+/8a	–	6c+	yes	21
12	7c	7a+	7c	7a	yes	4
13	7c	7b	7b+	7b	yes	11
14	7a+	6b+	7a+	6b+	yes	13
15	8b	7c	8b	7b	yes	12
16	7c	–	7a	–	yes	9
17	7c+	7b	7c+	7b	yes	21
18	8a+	7c	8a	7b+	yes	15
19	6b	–	6a	–	no	6
20	8c	8b	8c	7b	yes	10
21	7c+	7b	7c	7a	yes	36
22	6b	–	6a	–	no	12
23	8a+	8a	8a+	7c+	yes	10
24	7a+	7b	7a+	7b	yes	8
25	7c	7c	7b+	7c+	no	8
26	8c	8b	8c	8b	yes	20

Table 2: Reported climbing abilities between 6b and 9a in rope climbing and 6b and 8b bouldering on the fb scale.