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ORIGINAL RESEARCH

Persistent Unilateral Force Production Deficits following Hand Injury in Experienced Climbers: A Reliability and Retrospective Injury Study

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Introduction—In climbing, research is needed to guide clinical and training advice regarding strength differences between hands. The objectives of this study were to establish test-retest reliability of a field-based apparatus measuring sport-specific unilateral isometric hand strength and to investigate whether these measures detect between-hand differences in climbers with and without a history of unilateral hand injury.

Methods—A reliability and case-control injury study was carried out. Seventeen intermediate-advanced climbers without and 15 intermediate-advanced climbers with previous unilateral hand injury participated. Unilateral isometric fingertip flexor strength was assessed during maximal voluntary contraction (MVC) and peak rate of force development (RFD) tests in full-crimp overhead position. The magnitude of within-group between-hand differences was calculated using a generalized estimating equation to evaluate if prior injury was associated with lower MVC and RFD outcomes and whether hand dominance influenced the magnitude of these effects. The control group was assessed 1 wk later to determine intraclass correlation coefficients (ICCs) for all measures.

Results—The MVC (ICC 0.91–0.93) and the RFD (ICC 0.92–0.83) tests demonstrated moderate-to-high reliability. When accounting for handedness, those with prior injury showed 7% ($P=0.004$) reduced MVC and 13% ($P=0.008$) reduced RFD in the injured hand. The nondominant hand was also significantly weaker in MVC (11%, $P<0.001$) and RFD (12%, $P=0.02$) outcomes. For uninjured climbers, MVC and RFD were not significantly higher in the dominant hand (differing by 4% and 5%, respectively).

Conclusions—Previous climbing injury was associated with persistent weakness in the injured limb and exacerbated handedness effects. Therefore, recommendations for rehabilitation should be considered.

Keywords: rate of force development, sport-specific test, field test, handedness, fingertip strength

Introduction

The growing popularity of climbing is seeing an increase in climbing-related injuries. Incidence rates as high as 13 injuries for every 1000 h of climbing have been reported.[1] Higher training volumes compound the risk of injury, indicating that the most at-risk group is experienced climbers.[2] More than 81 to 93% of all climbing-related injuries occur in the upper extremity, with the hand and fingers being the most frequently injured (36–52%)[1,3,4] and reinjured,[5] with pulley injuries being the most common finger injuries.[3] Indeed, injuries to the fingers because of climbing outweigh all other injury locations, and it is suspected that many go undiagnosed and untreated.[6]

The "full-crimp" grip technique (Figure 1a) is associated with the greatest likelihood of hand injury during climbing.[6,7] This association is due, in large part, to the

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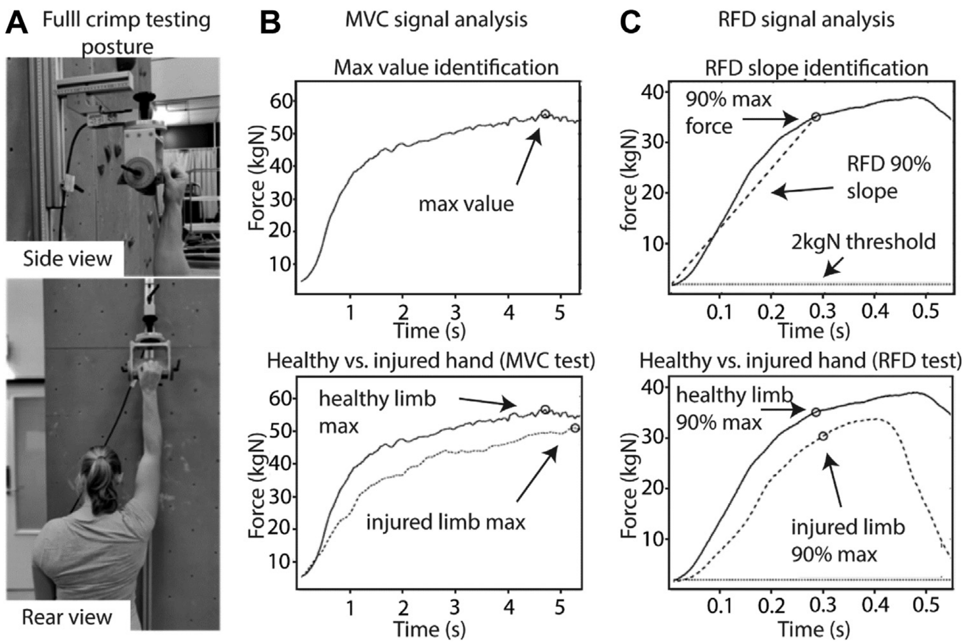

Figure 1. Testing posture, apparatus, and signal processing (see Supplementary Table 2 for equations). A, Side and back view of the overhead full-crimp grip position on the testing apparatus. The bottom image shows the climbing-specific position with the arm positioned overhead. Testing with the arm positioned overhead is considered more specific to climbing. When compared with elbow fixed testing positions, the overhead position has been more strongly associated with ability level, for instance. B, Examples of signals and analysis for the maximum voluntary contraction (MVC) test. Signals shown are of a healthy (solid line) and previously injured (dashed line) limb of the same individual during the MVC test. Circular markers are the maximum values, that is, the MVC. C, Examples of signals and analysis for the rate of force development (RFD) test. The healthy (solid line) and previously injured (dashed line) limb RFD is depicted. The dotted line indicates the 2 kgN threshold. The circular markers denote the point at 90% of the maximum. The slope of the solid and dashed straight lines are the RFD values used throughout this article.

large forces the finger flexor tendon pulleys deal with in full-crimp compared with that in other common grasping techniques.[3,8-13] In practice, avoiding the use of the full-crimp is not feasible because the large forces also support higher levels of climbing performance. For instance, climbing/sport-specific tests of full-crimp isometric force production during maximal voluntary contraction (MVC) tests strongly predict climbing performance (Figure 1a).[13-15] Hence, because of the associations among climbing-specific fingertip strength, performance/ability level, and injury risk,[10,14,16,17] it is of significant practical concern to climbers and their therapists following injury to recover (and perhaps further enhance) full-crimp strength.

Currently, laboratory-based instruments (eg, magnetic resonance imaging, radiography, and ultrasonography) or subjective criteria have been used to diagnose and monitor hand strength and its recovery after injury.[18] For instance, strong correlations between the extent of damage (as determined by ultrasonography) and force production have recently been uncovered, highlighting that force production tests can be clinically relevant and practical tools for monitoring hand injury in climbers.[19]

Unfortunately, very little is known about the strength-related consequences of injury to the hand to the climber and ways in which strength may change through rehabilitation and training, or the lack thereof. This is partly because field-based tests require specialized equipment and analysis of force-time curves (Figure 1).

Nonetheless, 2 tests have been developed in field settings for investigating climbing-specific hand strength: first, isometric maximal force production at the fingertips (MVC, Figure 1b) and, second, fingertip isometric rate of force development (RFD, Figure 1c). In support of their validity, MVC and RFD are generally higher in elite climbers than in beginners and intermediate climbers and can also be improved by climbing-specific training interventions.[16,20-22]

The objectives of this research were twofold. First, to establish test-retest reliability of a novel field-based apparatus measuring sport-specific isometric hand strength in terms of MVC and RFD. Second, to investigate whether these measures detected between-hand differences in climbers with and without a history of unilateral hand injury.

Methods

Power analysis prior to the study with a beta set to 0.8 revealed that 12 participants for within-group comparisons were required and 26 participants for between-group comparisons (14 participants per group) were required for large (d>1.0) and statistically significant (P<0.05), effects (the effect size estimate is based on that for a previous study[20]).

Male and female adult (>18 y) intermediate-advanced indoor climbers[23] with and without previous unilateral hand injury were recruited to participate. The study took place in The Netherlands, and all participants were approached in indoor climbing gyms that offered lead (rope-protected) and boulder (not rope-protected) style training. Both lead and/or boulder-focused climbers were eligible. Climbing ability data were collected using self-reported[24] current lead and boulder red-point French Sport scale (where red-point represents the highest graded route climbable with practice). The highest red-point was then converted to the International Rock Climbing Research Association scale for statistical analysis to verify if the groups were skill-matched.[25]

Participants were recruited to the previously injured group based on the presence of previous climbing-related injury to a single hand. For previously injured participants, the time elapsed from the injury event to the measurement was limited to between 6 and 9 mo.[26] Eligibility criteria further required that the injury diagnosis be confirmed by a physical therapist. Additionally, treatment and/or advice for specific exercises had to have been given by the physical therapist. The injury and general treatment histories were collected (see Supplementary Table 1). For the control participants, the injury-related inclusion criterion required (self-reported) absence of injury during the preceding 12 mo.[26]

Climbing ability, age, sex, volume of training, years of climbing experience, and anthropometrics were also collected to confirm that groups were matched on these variables (outcomes are summarized in Table 1). The research project was approved by the Vrije Universiteit ethics committee (reference id: VCWE-2018-080). All participants received written information and provided fully informed written consent before participating.

To measure the grip strength of the participants, a previously validated and reliable climbing-specific hand grip dynamometer[27] was used (Figure 1a). The system measures the force applied by the climber while using the hands in a climbing-specific manner. The system is portable and easily (re)mounted to a standard indoor climbing wall. Fingertip force was obtained by a single point load cell (Mettler-Toledo MT1241-250 kg, Columbus, OH) sampled at 1000 Hz with a National Instruments Compact-DAQ system (NI 9218, Austin, TX).

Table 1. Participant characteristics

Characteristic	*Previously injured (n=15)*	*Control (n=17)*
Age (y)	30.9±1.6	30.8±2.4
Sex (% male)	73	81
Weight (kg)	67.5±1.8	70.2±2.1
Height (cm)	177±2	177±2
Indoor red-point[a]	15 IQR=15 to 17	17 IQR=15 to 19
Experience (y)	5.2±1.7	7.8±1.6
Training ($h \cdot wk^{-1}$)	9±1	9±2
MVC (kgN)	494±33	523±35
RFD ($kgN \cdot s^{-1}$)	1559±274	1514±308

IQR, interquartile range; MVC, maximal voluntary contraction; RFD, rate of force development.

Mean±SD or median with IQR reported. Between-group comparisons revealed no significant differences on any of the participant characteristics.

[a]International Rock Climbing Research Association scale used (median and IQR given).

All tests occurred in climbing gyms where the instrument was mounted to indoor walls perpendicular to the ground plane. A standardized warm-up of 10 min was conducted, followed by 10 min of free climbing to prepare the muscles and joints for testing. The participants were requested not to train for at least 24 h prior to testing. For familiarization, participants performed a series of submaximal trials for each hand using the MVC and RFD test procedures.

The experimental protocol was then performed separately for each hand for both the MVC and RFD tests. The order of the execution of the hand and test type was randomized. For all tests, the grip height was adjusted to the body height of the participant with their arm extended to ensure consistency across participants and no discomfort during fingertip contractions. Participants were required to place themselves underneath the device where the measured hand was positioned onto the device such that the raised arm had to be held in line with the leg of the same side. Tests were done using the full crimp with the distal phalanges positioned on the edge and the thumb braced over the index and middle fingers. The ipsilateral foot was positioned above a mark perpendicular to the device's midline, while the opposite foot had to be positioned parallel at shoulder width apart. Concurrent visual feedback of the force signal was available for all tests.

During the MVC test, participants were instructed to "squeeze the grip as hard as possible." After the "go" signal, participants could release their body mass to the ground without any trunk or leg restriction. Moreover, they were invited to continue until they felt their maximum was reached. The elbow was required to be maintained in an extended position during the exertion. At least 2 valid tests were registered for each hand.[28] See Supplementary Table 2 and Figure 1b for data processing and computations related to the MVC test.

The RFD test instructions were "contract as fast and as hard as possible." The elbow had to be extended during the exertion. This was done to isolate the finger contraction. Additionally, the knees had to be maintained extended and stable and the trunk and hips firm to avoid the registration of additional power. At least 3 valid tests were registered for each hand. Prior to each contraction, participants were also required to achieve a 2 kgN threshold of precontraction.[21] See Supplementary Table 2 and Figure 1c for data processing and computations related to the RFD test.

The participants in the healthy group were followed up after 1 wk to confirm test-retest reliability in field settings (noting the system's reliability had been established in a laboratory setting[27]). The MVC and RFD tests were repeated for each hand using the above-mentioned procedures by the same operator. The tests performed on the second occasion were used for comparisons made against the injured group.

Prior to analysis, the normality of the data for each test for the RFD and MVC was verified. Reliability for the MVC and RFD for each hand was tested using intraclass correlation coefficients (ICCs) using an average measure (ie, the average of 2 tests per hand for the MVC test and the average of 3 tests per hand for the RFD test) random effects model.[29] To consider if the prior injury was associated with lower RFD and MVC capability, a generalized estimating equation (GEE) procedure with main effects, using a Gaussian normal distribution, identity link function, and exchangeable correlation structure, was used. All valid tests were included in the GEE procedure (ie, 2 trials per hand for the MVC test and 3 trials per hand for the RFD test). Hand dominance was considered a possible covariate.[20] For group-wise comparisons and exploratory analyses, t tests with Cohen's d effect sizes were reported, where d values between 0.2 and 0.49 were defined as a small effect, d values between 0.5 and 0.79 as a moderate effect, and $d \geq 0.8$ as a large effect. As with the ICC analysis, within and between analyses were performed on the average of valid tests. Analysis was completed in R version 3.6.3 (R Core Team, 2013).

Results

Seventeen healthy and 15 previously injured climbers agreed to participate, forming the 2 groups. Participant characteristics are summarized in Table 1 (noting that unless otherwise stated, data are presented as mean±SD).

Raw P values showed no significant differences in any between-group participant characteristics, including overall mean (across both hands) MVC and RFD force-producing capability, climbing ability level, discipline focus, years of experience, sex, age, weight, height, or current training volume. The skill level of the entire sample of climbers ranged from intermediate to advanced. Eight climbers in each group split their training across lead and bouldering, 7 in each group focused primarily on bouldering, and 2 participants in the control group focused on lead. Pearson's χ^2 test showed no significant differences between the groups related to discipline focus. Finally, of the previously injured climbers, 9 injured their dominant hand and 6 injured their nondominant hand.

High test-retest reliability was found for both hands on the average outcomes of the MVC scores for each hand (left ICC [2,2]=0.91, 95% CI [0.76, 0.96]; right ICC [2,2]=0.93, 95% CI [0.83, 0.97]). Moderate-to-high reliability was found for the RFD tests for each hand (left ICC [2,3]=0.92, 95% CI [0.749, 0.971]; right ICC [2,3]= 0.83, 95% CI [0.53, 0.94]).

The GEE analysis for the previously injured group revealed that injury was a significant predictor for MVC and RFD in each case when adjusted for the covariate hand dominance (which was also significant) (Table 2). For each outcome (MVC and RFD), the regression equation was constructed by first including the predictor *injury* (uninjured vs previously injured hand). For both outcomes, this predictor alone was not significant. Adjustment for hand dominance, by adding the covariate *hand dominance* in the regression equation, then revealed a significant effect of injury (7% reduced MVC in the injured hand, P=0.004; 13% reduced RFD in the injured hand, P=0.008) and dominance (11% increased MVC in the dominant hand, P<0.001; 12% increased RFD in the dominant hand, P=0.02).

The prediction equations for MVC and RFD for the control group were also examined, testing only the effect of hand dominance (Table 3). The GEE analysis revealed no significant effect for hand dominance when predicting the MVC and RFD. The MVC was predicted to be 4% higher for the dominant hand (P=nonsignificant), and the RFD was predicted to be 5% higher for the dominant hand (P=nonsignificant).

An exploratory analysis of the previously injured group was then carried out. The injured and uninjured hands were compared for the MVC test (467±110 kgN vs 485±101 kgN, respectively) and the RFD test (1076±317 kgN·s^{-1} vs 1188±334 kgN·s^{-1}, respectively). In line with the GEE analysis, neither comparisons were significant.

Table 2. Injured group GEE analysis of the MVC[a] and RFD[b] test coefficients. Coefficients: injured hand=1, uninjured hand=0, dominant hand=1, and nondominant hand=0

	MVC coefficients±SE (kgN)	P	*z-score*	*RFD coefficients±SE (kgN·s^{-1})*	P	*z-score*
Injured	−33±12	0.004	−2.84	-167±63	0.008	2.64
Dominance	53±12	0.001	4.57	149±63	0.02	2.35
Intercept	466±24	-	-	1243±104	-	-

GEE, generalized estimation equation; MVC, maximum voluntary contraction; RFD, rate of force development.
[a]Injured group: number of observations=60, number of participants=15; observations per limb=2.
[b]Injured group: number of observations=90, number of participants=15; observations per limb=3.

Table 3. Control group GEE analysis of the MVC[a] and RFD[b] test coefficients. Coefficients: dominant hand=1 and nondominant hand=0

	MVC coefficients±SE (kgN)	P	*z-score*	*RFD coefficients±SE (kgN·s^{-1})*	P	*z-score*
Dominance	19±10	0.06	1.91	66±74	0.39	0.86
Intercept	515±19	-	-	1431±146	-	-

GEE, generalized estimation equation; MVC, maximum voluntary contraction; RFD, rate of force development.
[a]Control group: number of observations=72, number of participants=18; observations per limb=2.
[b]Control group: Number of observations=108, number of participants=18; observations per limb=3.

To explore how hand dominance may have influenced injury effects, we then created 2 subgroups based on whether the injury was to the dominant hand (n=9 participants) or nondominant hand (n=6 participants). The outcomes and relevant comparisons between hands for the MVC and RFD tests for the previously injured groups are presented in Table 4 (significant raw *P* values and large effect sizes are shaded).

Starting with the within-group comparisons, a large significant effect in the MVC outcome (18% difference, adjusted P=0.004, *d*=1.24) was found between the hands in the participants that previously injured their nondominant hand. In this same subgroup, after adjusting for multiple comparisons, the RFD outcome was not significant (25% difference, ns), although it did show a large effect (*d*=0.82). In the subgroup of participants who injured their dominant hand, there were no significant or sizable differences between hands in the MVC (1% difference, P=ns, *d*=0.18) or RFD (6% difference, P=ns, *d*=0.05) outcomes.

Group-wise comparisons were also performed. After adjusting for multiple comparisons, large but insignificant differences between the group that injured their dominant hand and the group that injured their nondominant hand were shown when comparing the MVC outcomes in the injured limb (21% difference, P=ns, *d*=1.58) and RFD outcomes in the injured limb (21% difference, P=ns, *d*=0.99). There were no significant or sizable differences between the subgroups in either outcome when comparing healthy hands (Table 4).

Finally, in the control group, within-group comparisons (Table 5) showed a small but insignificant difference between the dominant hand and nondominant hand for the MVC test (the dominant hand was on average 4% stronger [P=ns, *d*=0.23]). No sizable or significant effect was shown for the RFD test (the dominant hand was, on average, stronger by 7% [P=ns, *d*=0.15]).

Discussion

The findings of this study are, first, that a field-based climbing-specific apparatus was moderately-to-highly reliable in unilateral tests of maximal isometric strength (MVC test) and isometric explosive strength (RFD test) for each hand. Second, when adjusting for hand dominance, individuals with prior hand injury showed significant strength deficits in the previously injured hand compared with those in their contralateral uninjured hand both in the MVC and RFD tests. Finally, large and significant between-hand differences for MVC were found in individuals who injured their nondominant hand but not found in individuals who injured their dominant hand.

The test-retest reliability of this field-based instrument is comparable to that of previous investigations that have used laboratory-based measurement equipment and environments.[30-32] While other field-based studies have shown good reliability when assessing climbing-specific hand strength,[31,33,34] the current test has several advantages (and points of difference). First, the test uses a climbing-specific posture with the arm extended overhead compared with protocols of tests with a fixed elbow.[31] Second, the unilateral testing procedure allows

Table 4. Injured dominant hand vs injured nondominant hand comparisons

	Dominant hand injured (n=9)				*Nondominant hand injured (n=6)*				*Between comparisons*		
	Within comparisons				*Within comparisons*						
	Mean±SD	*t^*	*Raw* P	d	*Mean±SD*	*t^*	*Raw* P	d	*t*[a]	*Raw* P	d
MVC injured hand (kgN)	509±114	1.73	0.12	0.18	400±69	4.02	0.002	1.24	3.24	0.04	1.58
MVC healthy hand (kgN)	489±105				486±91				0.06	0.95	0.03
RFD injured hand ($kgN·s^{-1}$)	1318±336	0.21	0.84	0.05	937±385	2.93	0.03	0.82	2.14	0.06	0.99
RFD healthy hand ($kgN·s^{-1}$)	1336±423				1253±384				0.42	0.69	0.22
Training ($h·wk^{-1}$)	7.6±3.3				9.8±4.0				1.12	0.28	0.55
Therapy sessions (total)	7.6±3.3				9.3±3.1				1.01	0.33	0.55

MVC, maximum voluntary contraction; RFD, rate of force development.

t^=Paired t test

All within and between analyses were performed on the average of the valid tests.

[a]Welch 2 sample t test for unequal sample sizes used; *d*=Cohen's *d*, such that for dependent tests: $Mean_{Healthy}$-$Mean_{Injured}$/$SD_{Injured}$ and for independent tests: $Mean_{DominantInjGroup}$-$Mean_{NondominantInjGroup}$/$SD_{NondominantInjGroup}$.

Table 5. Healthy group summary outcomes (n=17)

	Dominant hand	*Nondominant hand*			
	Mean±SD	*Mean±SD*	*t^*	*Raw* P	d
MVC (kgN)	534±86	515±83	1.85	0.08	0.23
RFD ($kgN·s^{-1}$)	1497±646	1399±633	0.21	0.84	0.15

All comparisons were performed on the average of the valid tests.

MVC, maximum voluntary contraction; RFD, rate of force development

t^, paired t test; *d*, Cohen's *d*, such that for dependent tests: $Mean_{DominantLimb}$-$Mean_{NondominantLimb}$/$SD_{NondominantLimb}$.

evaluation of between-hand differences, whereas bilateral procedures do not.[33] Finally, the current system captures high-frequency force-time data for analysis, whereas some previous instruments obtain only a single data point[34] (meaning RFD cannot be obtained).

Our study did not show significant differences between dominant and nondominant hands in the MVC or RFD outcomes in healthy climbers. Two studies have previously tested for and reported hand dominance effects in healthy climbers using hand grip dynamometers with reported differences of approximately 10%.[35,36] The hand grip dynamometers have been previously shown to be unable to differentiate between climbers and other athletes (which is why fingertip strength is considered a more appropriate measure of sport-specific strength). As the studies mentioned earlier did not use a climbing-specific test, this may explain the differences in our results. It is also worth mentioning that other studies have reportedly used unilateral climbing-specific tests involving climbers but have only either tested a single hand or reported the average of both hands[1,10,20,31,32,34,37-39]; hence, they cannot be compared with our results. Indeed, in the current study, when taking the average MVC and RFD across both hands, there were no group differences shown between previously injured and uninjured climbers (Table 1). This reinforces the importance of unilateral testing for evaluating hand injury in climbers. Our findings indicate that healthy climbers have a low (approximately 0.2 SD) difference between hands for MVC and RFD outcomes, which might be used as a benchmark for "healthy" interhand differences or a target for rehabilitation after injury.

We found that previously injured climbers show hand dominance effects not shown in the healthy group. When controlling for hand dominance, persistent deficits were revealed for MVC and RFD outcomes in the injured hand compared with those in the uninjured contralateral hand. Furthermore, the exploratory analysis uncovered that force production deficits may be dependent on which hand was injured (Figure 2). Climbers who injured the nondominant hand had large deficits in both MVC and RFD compared with the contralateral uninjured dominant hand (although only the MVC was significant, which is likely due to the small sample size that the subgroup analysis was based on).

Without other studies for comparison, these findings may have been related to our climbing-specific testing procedures, the relatively high sample rate (1000 Hz), and/or the availability of real-time feedback during the tests. An alternative candidate explanation for persistent deficits is a suboptimal in situ training intensity in the 6 to 9 mo following the injury event. According to this hypothesis, individuals who injure their dominant hand might return to in situ (ie, climbing-specific) training at levels of intensity that are more optimal for recovery than individuals who injure their nondominant hand. There are several points of evidence supporting this. First, there is a lack of relationship between nonspecific and climbing-specific grip strength tests, suggesting that climbing-

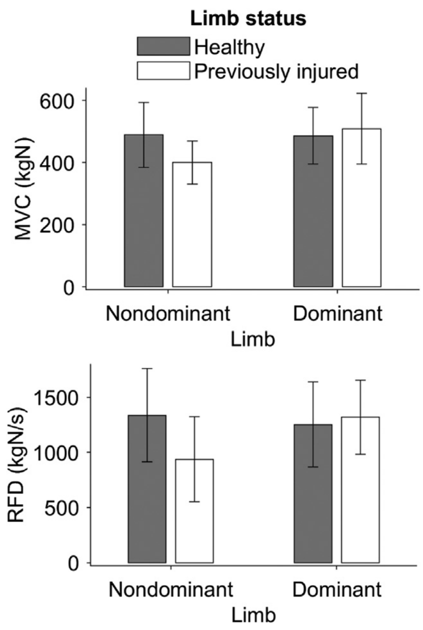

Figure 2. Main and interaction effects between hand dominance and injury status across the maximal voluntary contraction (MVC) and rate of force development (RFD) outcomes for the injured participants. Error bars=SD.

specific training is required for the rehabilitation of climbing-specific strength (ie, fingertip strength).[13] Second, there was no significant difference in training frequency or number of physical therapy sessions between subgroups in this study (Table 4). This suggests that insufficient training intensity at the injured hand might better explain the persistent deficit (or at least would rule out insufficient training frequency). Third, there is an absence of hand dominance−mediated cross-education effects in our data. Typically, if the dominant hand is trained and the nondominant hand is immobilized, loss of strength can be prevented in the immobile nondominant hand, but not vice versa.[40] In this study, however, climbers who injured their nondominant hand continued to train with their healthy dominant hand, yet showed loss of strength in the injured nondominant hand. These points suggest that insufficient intensity during climbing-specific training of the healthy dominant hand is a candidate cause of persistent strength deficit.

FUTURE RESEARCH AND PRACTICAL IMPLICATIONS

Given the potential link between hand strength asymmetries and injury risk,[41] future research should investigate optimal approaches to addressing persistent strength imbalances following hand injury in climbing. As a starting point, magnitudes of strength differences of approximately 0.2 SD in MVC and RFD outcomes during climbing-specific testing may be considered "healthy" (as these are the levels shown in the healthy group, Table 5). In terms of considering rehabilitation strategies, our study implies that more aggressive and/or alternative interventions are needed for climbers who injure their nondominant hand. Current recommendations in treating climbing injury advocate "pain-free" return to activity.[6,28] In contrast, it may be possible that more aggressive (higher intensity) treatment can be beneficial. For example, "pain-threshold" rehabilitation has demonstrated some better outcomes than traditional "pain-free" intervention (at least during lower limb muscle strain rehabilitation).[42] Finally, strength/skill training of different grip types, other than only full crimp, might support a more rapid/safe return to high-intensity in situ training and, in doing so, potentially ameliorate persistent postinjury strength deficits (as discussed previously[27]).

Other lines of research might also target alternative mechanisms for explaining why climbers reduce the intensity of in situ training following injury, particularly when they injure the nondominant hand. In coordination studies, for instance, training the nondominant hand can improve the coordination of the dominant hand but not vice versa. Because skill influences training intensity, interhand differences in coordination may be a potential mechanism of persistent weakness.[43] For example, injury to the nondominant hand may cause reduction in skill and/or self-efficacy, leading to in situ training intensities that are not sufficient for full recovery.[44] Finally, pain is also perceived more intensely in the nondominant hand.[45] It is possible that some kind of pain-mediated neural inhibition interferes with the capability to recruit at intensities sufficient to stimulate recovery (a candidate mechanism in unilateral lower limb muscle strain injuries[46]), subsequently causing prolonged strength deficits in some climbers.

Limitations

The current study has several limitations. First, the study required participants to self-rate their climbing ability levels; thus, their level of climbing ability was not determined using an objective climbing test. Second, retrospective injury history and details of rehabilitation were based on subjective reporting. As a result, the characteristics of previous hand injury and the specificity and intensity of rehabilitation treatments postinjury are unknown, with these factors being positioned as the most likely to influence strength. Third, while we position any strength deficit as being caused by previous injury, as with any retrospective investigation, it is unknown whether between-hand deficits caused or were caused by the initial injury.

Conclusions

Previous climbing injury was associated with persistent weakness in the injured hand and exacerbated handedness effects. Furthermore, a healthy control group showed minimal differences in MVC and RFD. Climbers who injured their nondominant hand also showed large deficits in that hand compared with any in their contralateral dominant hand. However, between-hand differences in strength are not shown in climbers who injure the dominant hand. Therefore, it is recommended that climbing-specific treatment approaches that emphasize climbing-specific and (safe) high-intensity hand and fingertip muscle recruitment should be prioritized for both the injured and uninjured hand following injury. Healthy between-hand differences in strength of approximately 0.2 SD would align with what we observed in healthy controls. Future work should replicate our findings with a larger sample of individuals who injure their dominant hand and nondominant hand. Potential mechanisms that may explain persistent strength deficits following hand injury in climbing should also be investigated, including skill deficits, motivation, pain, and rehabilitation strategy.

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Disclosures: None.

Appendix A. Supplemental Material(s)

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.wem.2022.10.001.

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