The rate of force development: a new biomechanical key factor in climbing

Guillaume LEVERNIER[1, 2] and Guillaume LAFFAYE[1,2],

1 - CIAMS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay Cedex, France

2 - CIAMS, Université d'Orléans, 45067, Orléans, France

Guillaume LEVERNIER, Laboratoire Contrôle Moteur et Perception, Université Paris-Sud,

Bât 335, 91405 Orsay Cedex, France

E-mail: guillaume.levernier@u-psud.fr

Abstract:

The goal of this study was to show the importance of the rate of force development in rock climbing. It is composed of two sub-studies. In the first one, we investigate the difference of maximal force and RFD between elite, skilled and novice climbers. The difference in RFD_{200ms} and $RFD_{95\%}$ among the three groups suggests that the practice of intensive climbing causes many changes in neural and structural factors. Last, RFD_{200ms} is highly reliable and can be used to discriminate samples, suggesting that these variable could be used in monitoring training.

In the second one, we focused on the elite and world top ranking climbers and assess the impact of a specific 4-week training program on the maximal force and the RFD of finger muscles in isometric contraction. These results reveal that a 4-week training program is enough to improve the level of maximum force at the finger and the RFD_{200ms}. Bearing in mind that climbing will make its appearance in a future Olympic Games in the form of a combined competition, i.e., bouldering, speed climbing, and lead climbing, it will be crucial for each athlete to develop both a high level of force and RFD to be competitive.

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Key words: World top ranking, finger, maximal force, training, isometric contractions

Résumé

L'objectif de cette étude est de montrer l'importance du taux de développement de la force (RFD) en escalade. Elle est composée de deux sous études. Dans la première, nous regardons les différences au niveau la force maximal et du RFD entre les grimpeurs élites, confirmés et novices. Les différences pour le RFD_{200ms} et le $RFD_{95\%}$ entre les trois groupes suggèrent que la pratique intensive de l'escalade engendre de nombreux changements au niveau du facteur structural et nerveux. De plus, le RFD_{200ms} est très fiable et peut être utilisé de façon à discriminer les populations ainsi qu'indicateur de la performance.

Dans la seconde étude, nous nous sommes intéressés aux grimpeurs de niveau national et international et avons regardé l'impact d'un entraînement spécifique sur la force maximal et le RFD au niveau des muscles fléchisseurs des doigts à la suite de contractions isométriques. Les résultats révèlent que 4 semaines sont suffisantes pour améliorer le niveau de force au niveau des doigts ainsi que le $RFD_{200ms.}$ En gardant à l'esprit que l'escalade fera son apparition aux prochains Jeux Olympiques sous la forme d'un combiné incluant la difficulté, le bloc et la vitesse, il semble indispensable pour chaque athlète de développer à la fois un haut niveau de force et à la fois le taux de développement de la force.

Mots clefs : sportif de niveau international, doigts, force maximale, entraînement, contractions isométriques

Introduction

Rock climbing is sport with a combination of mental factor, strength and power of upper-limb, technique and anthropometric characteristics, as suggested by several studies (Magiera et al., 2013). For instance, Laffaye et al reveals that climbing ability could be assessed by three components, labeled as training, muscle, and anthropometry, which together explain 64.22% of the total variance. The regression model indicates that trainable variables explained 46% of the total variance in climbing ability (Laffaye, Levernier, & Collin, 2015). Within the training variables, the finger grip strength is highly determinant of the skill level. The literature shows the importance of finger grip strength in bouldering, which seems to be a key variable for raising the elite level. Typical time for a bouldering attempt is about 30 seconds with an effective static phase of 7.5 seconds and a dynamic phase of 22.5 seconds (White & Olsen, 2010), made up of explosive movements that require the grip to hold as strong and as fast as possible. In this context, the way the force is produced seems crucial. The change in force over time, namely the rate of force development (RFD in $N.s^{-1}$), is highly dependent on the slope of the force until the maximal value or a percentage of this value. Increasing the level of finger flexor strength and the RFD with training seems crucial for improvements in performance.

This study is composed of two sub-studies. In the first one, we investigate the difference of maximal force and RFD between elite, skilled and novice climbers. In the second one, we focused on the elite and world top ranking climbers and assess the impact of a specific 4-week training program on finger grip in climbers; specifically, on the maximal force and the RFD of finger muscles in isometric contraction.

1. Effect of the maximal strength in finger between and the RFD for elite, skilled and novice climbers

Method

Thirty-one subjects were divided into three groups according to their skill levels based on the French Fb rating (Fb corresponds to Fontainebleau, a rating scale used in bouldering). They were categorized as novice (< 5c), skilled (7c-8a) or elite (≥ 8b). A PGM dynamometer calibrated at a frequency of 1000 Hz was used to measure maximal force and RFD. Anthropometrical data (weight, percentage of fatty and muscular mass) were recorded using a Tanita BC 545n InnerScan anthropometer. Two different holds were selected (i.e., the slope crimp, half crimp). The slope crimp is characterized by a flexion of the distal interphalangeal (IPD) and a little flexion of the proximal interphalangeal (IPP). For the half crimp, the angle of the IPP is 90° with an extension for the IPD. They were instructed to squeeze the device as tightly and as quickly as possible with each hand three times (Maffiuletti et al., 2016). RFD was measured at three typical time scales: 50 ms, 100 ms and 200 ms, called respectively RFD_{50ms}, RFD_{100ms} and RFD_{200ms}, and at 95% of the Fmax ($RFD_{95\%}$).

The intraclass correlation (ICC) and coefficients of variation were calculated intra-session for all three trials in each condition. To assess the difference between samples, a one-way analysis of variance was performed (ANOVA) with a Fisher post-hoc test and power (1-β). Significance was set at $p<0.05$.

Results and discussion

Intra-session reliability reveals ICC ranging from 0.94 to 0.99. CV ranged from 9.81% to 22.96% for RFD and from 3.79% to 6.97% for Fmax. Inter-session reliability revealed no difference (all T<1). The coefficients of correlation between the first and second sessions ranged from 0.60 to 0.96 ($p<0.01$; η^2 between 0.35 and 0.92) with high correlations (>0.80) for the following variables: Fmax, $RFD_{95\%}$ (right slope crimp), RFD_{200ms} (left and right half crimp), RFD_{100ms} (left and right half crimp) and RFD_{50ms} (right slope crimp and left half crimp). Maximal force, expressed as an absolute or normalized value, reveals a significant difference for all conditions. The post-hoc Fisher test reveals a difference among all samples ($p < 0.01$). RFD shows differences with respect to the time scale, as revealed by Figure 1.

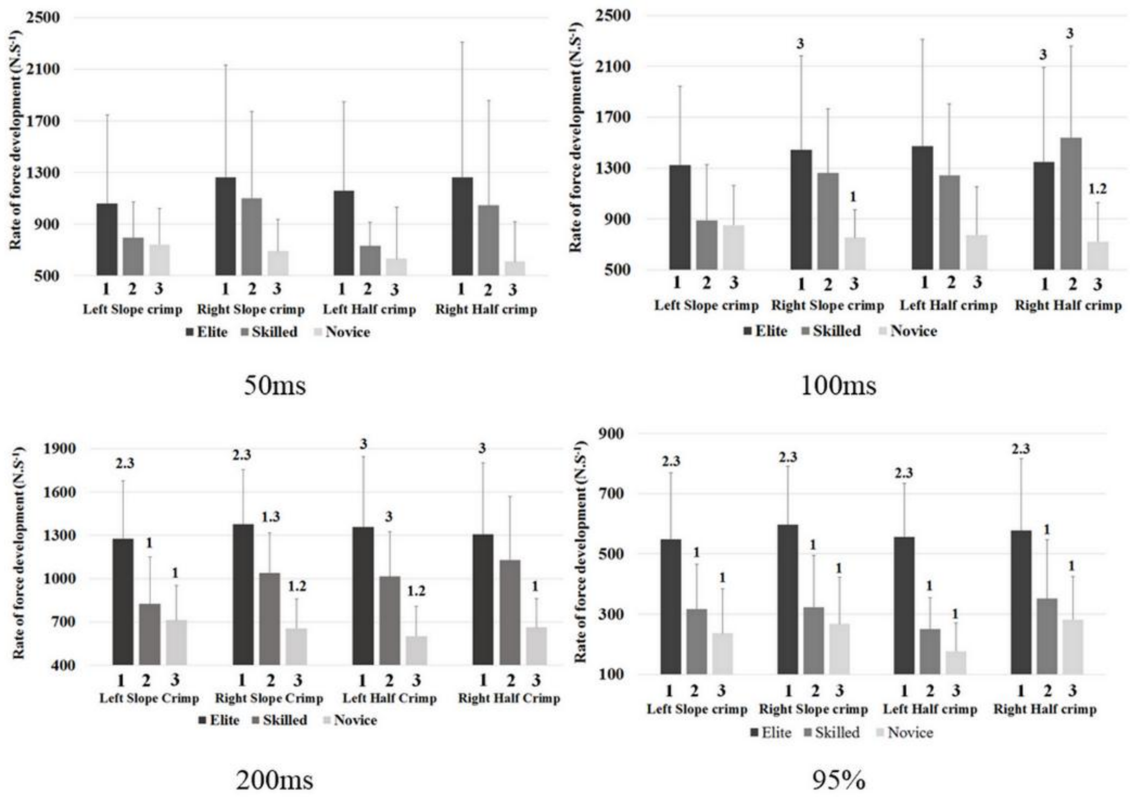

Figure 1 - Difference between three samples for RFD_{50ms}, RFD_{100ms}, RFD_{200ms} and $RFD_{95\%}$ and for slope and half crimp. [1,2,3] when significant difference ($p<0.05$)

RFD_{200ms} reveals good reliability, with CV of 11.78% while the other RFD have CV greater than 14%. Moreover, RFD_{200ms} is more reliable than other RFD conditions including maximal force. Tillin et al. show that RFD_{50ms} is less stable than RFD_{200ms} (CV 14.6% for RFD_{50ms} versus 7.9% for RFD_{200ms}) (Tillin & Folland, 2013). Such variability could be explained by the high difference in neural adaptation with training. Postural regulation in a short time is a key moment in climbing and involves neural processes such as sensory feedback and reflex, and is a highly adaptive strategy in preventing falls.

Many differences were observed in RFD_{200ms} for all conditions between three samples: 24.6% between elite and skilled, 33.2% between novices and skilled, and 50.4% between elite and novice. Andersen et al. explain that RFD between 150 and 250 ms is highly dependent on either the contractile properties of the muscle-tendon unit, such as cross-section area and neural drive, or a combination of both. Climbing probably changes the intrinsic mechanical properties of muscles and tendons, especially the finger flexor, and the contraction mechanism linked to neural drive (Andersen & Aagaard, 2006). A correlation between Fmax and RFD reveals an $r^2=0.48$ for RFD_{200ms}. Considering that maximal force is linked with the muscle cross-section area (Cohen, Texier, Laffaye, Auvray, & Clanet, 2015), this contribution of maximal force confirms a recent study that showed a comparable correlation between explosive force at a comparable time course (150 ms) and maximal voluntary contraction ($R^2=0.90$). This confirms the crucial role of muscular properties in RFD (Andersen & Aagaard, 2006). For $RFD_{95\%}$, a 45.4% difference between elite and skilled, and 57.8% difference between elite and novice has been observed, meaning that elite climbers would be able to reach 95% of Fmax more quickly than the others. This two-times greater value found in elite climbers compared to skilled climbers and novices reveals their high level of adaptation in a wide variety of motions (fast and strong such as the "dyno" movement or explosive movement, including postural or reflex adaptation and slower movements) compared to skilled climbers.

2. Training increases the RFD and the maximal force in elite and top world-ranking climbers

Method

Fourteen French male rock climbers who take part in national and international bouldering competitions participated in this study. They were randomly divided into either the control group or the experimental group. Experimental followed a specific training and climb, control group just climb with no specific exercise. The training program was designed in conjunction with the French national team's coaches and was repeated 3 times a week for 4 weeks. In this training, climbers had to hold on as long as possible (between 1 and 6 seconds) without making contact between the foot and the ground. The other 3 training sessions involved regular exercises. The protocol did not change the frequency of training for both groups. Maximal force and RFD for three prehension (slope crimp, half crimp and full crimp) and anthropometrical data were assessed with the same procedure. The RFD was also measured from the onset to 200 ms ($RFD_{200\ ms}$) and 95% of the maximal force ($RFD_{95\%}$).

An analysis of variance (ANOVA) was performed with repeated measurements of the time (before and after training), with the group as an inter-subject factor and training as an intra-subject factor to compare the differences of gain between the 2 groups.

Result & Discussion

Normalized values did reveal a significant effect for the right slope ($F_{(1.12)} = 7.56$; $p= 0.02$). Fisher's test revealed an effect of training for the experimental group ($p= 0.03$) and in the post test between both groups. For the RFD, there is no significant difference in $RFD_{95\%}$ between the experimental and control groups. Concerning the $RFD_{200\ ms}$, difference was found for any conditions only for experimental group (table 1).

	Slope L	Slope R	Half L	Half R	Full L	Full R
Pre test	942.0 ± 314.7	978.3 ± 488.1	978.9 ± 363.9	995.5 ± 446.0	983.9 ± 405.9	1011.8 ± 513.7
Post test	1407.5 ± 259.2	1412.9 ± 513.5	1304.7 ± 491.5	1418.8 ± 510.8	1386.8 ± 428.9	1366.9 ± 407.1
Difference (%)	33.1*	30.9*	25.0*	29.9*	30.1*	26.0*

Table 1 - Result for RFD_{200ms} ($N.s^{-1}$) before and after training for experimental group. * when statistical difference at $p<0.05$. L for Left, R for Right.

The change of RFD_{200ms} is probably due to an increase in the motor unit discharge and the contractile impulse, as suggested by Aagaard et al. (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). A gain later in the force-time curve, i.e., in the second part of the RFD, is linked closely to changes in the tendon-muscle coupling and to the contractile properties of the muscle, which increase later in the RFD curve (Tillin, Jimenez-Reyes, Pain, & Folland, 2010). The RFD is a factor which is affected by training (Duchateau & Hainaut, 1984), before the maximal force is achieved. These indications are confirmed by Tillin et al. (Tillin & Folland, 2014), who explained that isometric-type exercises would improve muscle activation. Based on this idea, we can hypothesize that the specific training performed by climbers is primarily impacted by the neural factor and by a probable increase in the discharge of the motor units. Nevertheless, maybe structural factor would have can be able to evolved. Therefore, a 4-week training program is sufficient to increase the force and RFD for the finger flexor for both elite and top world-ranking boulderers (Levernier & Laffaye, 2017). This study reveals that there was an increase of the RFD_{200ms} for all the condition crimps, whereas the training plan was based on isometric contractions in the slope and half crimp grips, suggesting a possible transfer of force between the crimps. This result could help trainers to manage the gain of force and the prevention of injury. Indeed, the full crimp overloads the A2 pulley at maximum pressure, which could be broken when overused. Our study suggests that it is not necessary to work specifically on the full crimp grip to increase the force in this position; rather, working with the half crimp or the slope crimp grip can result in an increase in finger flexor force and rate of force for all grips.

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