EFFECT OF CLIMBING HOLD DEPTH ON BIOMECHANICAL ARM ACTION DURING PULL-UPS

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Abstract

Pull-ups are often used by sport-climbers and other athletes to train their arm capabilities. In an original way, sport-climbers use different types of holds to reinforce finger strength concomitantly. However, the effect of grip types on pull-up performance had not previously been investigated. This study used a vertical force platform sensor to measure the force exerted by climbers when performing pull-ups under six different grip conditions (gym-bar, large climbing hold, and four small climbing holds: 22mm, 18mm, 14mm, and 10mm). The electromyography of finger flexor and extensor muscles were recorded simultaneously. The maximal arm power and summed mechanical work were computed. The results revealed that the execution of pull-ups was strongly influenced by the grip conditions. More precisely, climbing hold depth and grip type had several effects on the execution of pull-ups, including maximal finger force application, finger flexor fatigue, and muscle control of upper-limb movements. These findings are likely to be useful for quantifying training loads more accurately and designing training exercises and programs.

Keywords: Biomechanics, Pull-up training, Arm power, Grip types

Résumé

Les tractions sont régulièrement utilisées par les grimpeurs pour entraîner les capacités musculaires des bras et des doigts. Contrairement aux autres sports, les grimpeurs utilisent différentes prises de préhension en utilisant des poutres d'entraînement en plus d'une barre de traction classique. Cependant, l'effet de la taille de prise sur les tractions n'a encore jamais été évalué alors que ce paramètre est crucial pour pouvoir évaluer les charges d'entraînements réalisées par les bras et les doigts. Cette étude vise à quantifier cet effet à travers l'évaluation de la puissance et du travail mécanique réalisé par les bras et de la cocontraction et de la fatigue des avant-bras selon les différents types de prises. Une plateforme de force verticale a été utilisée pour enregistrer la force exercée par les grimpeurs lors d'un exercice de traction maximal avec six différentes formes de préhension (une barre de traction classique, une prise d'escalade large et 4 petites prises : 22mm, 18mm, 14mm, and 10mm). L'électromyographie des muscles fléchisseurs et extenseurs des doigts était enregistré simultanément pour évaluer un indice de cocontraction et un indice de fatigue musculaire. La puissance et le travail mécanique ont été calculés à partir des signaux de force. Les résultats montrent que les tractions sont fortement influencées par le type de préhension. Plus particulièrement, le type de préhension peut modifier le travail mécanique et la puissance développés par les bras mais aussi les niveaux de fatigue des avant-bras et le niveau de co-contraction. Ces résultats peuvent permettre de mieux cibler les exercices à réaliser selon les objectifs que l'on veut atteindre en réalisant des tractions, c.a.d. développer la puissance, développer la résistance à la fatigue etc.

Mots clés : tractions, entraînement des bras, type de préhension, biomécanique

Introduction

Several previous studies have investigated climbers' finger and hand capabilities, revealing that climbers have enhanced capacities for exerting maximal forces with their fingertips (Cutts & Bollen, 1993, Quaine *et al.*, 2003) related to greater force-generating capacity of finger flexor muscles (Vigouroux *et al.*, 2016). Concomitant studies (Draper *et al.*, 2011) investigated the climbers' arm capabilities and demonstrated that elite climbers developed more power (around 1350W) during arm-jump exercises than novices (around 40W).

To train their arm and finger capabilities, climbers usually perform pull-ups (Youdas *et al.*, 2010). These exercises are also part of the usual training regimen for several other sports and previous analyses in the literature concerned non-climbers (Ricci *et al.*, 1988). One major difference between pull-ups for climbing objectives compared to fitness is the use of various types of grips, including gym bars, as well as large and small climbing holds. However, it was not previously known how the type of grip influenced the pull-up exercise, although this information is needed to quantify the loading on both the arms and fingers during these exercises. The aim of this study was thus to investigate mechanical parameters of pull-ups (especially the maximal forces applied, maximal power, and mechanical work) executed by climbers under various grip-type conditions.

Methods

Ten elite and higher-elite climbers (from French grade 7c to 8b+) volunteered to participate in the experiment (age: 21.4±2.6 years; body weight: 65.95±5.9kg; height: 175.6±4.5cm; hand size: 19.2±0.9cm). A specially designed force platform equipped with force sensors (strain gauges), was used to measure the vertical force applied by climbers on the grip support (Figure 1).

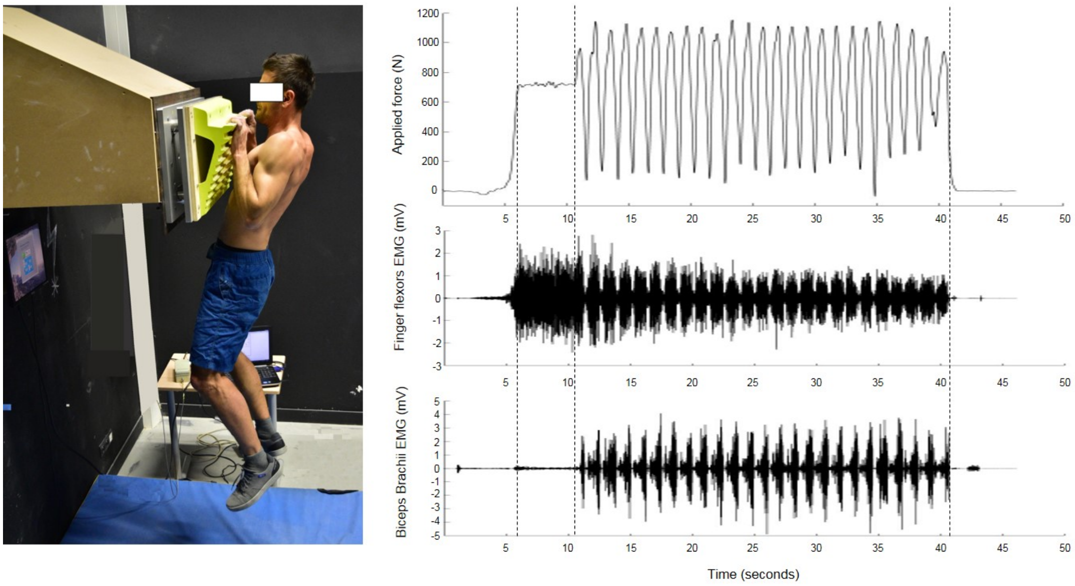

Figure 1. Experimental setup photo and raw data. The picture on left shows the experimental setup (vertical platform fixed on a rigid support) equipped with the commercial hangboard (yellow climbing hold), used to test the grip conditions, with the climbing holds (10mm, 14mm, 18mm, 22mm, and large-hold). The climber is currently hanging on the large-hold at the top of a pull-up. The graphs on the right show representative data of the vertical force (upper panel), Finger flexor EMG (middle panel), and Biceps brachii EMG (lower panel), recorded during one pull-up series. The moment when the subject was hanging immobile on the hold before starting the pull-ups is visible between the two dotted lines.

After a warm-up (climbing 2-3 routes of sub-maximal difficulties) and enough time to familiarize themselves with the test equipment, participants were asked to perform a series of maximal pull-ups. For each pull-up, they were required to start with fully-extended arms and finish with the chin level with the hold. For each series, the participants were asked to perform the pull-ups "as fast as possible" and "as strongly as possible" until exhaustion. Six grip conditions were tested: a gym-bar (2.5mm in diameter), a large climbing hold (>80mm in depth, i.e. larger than the length of the fingers from the metacarpophalangeal joints to the fingertips), and four small climbing holds, i.e. shorter than the length of the fingers (10mm, 14mm, 18mm and 22mm). EMGs of the Biceps brachii (BB), Triceps brachii (TB), finger extensors (Extensor digitorum communis, FE), and finger flexors (Flexor digitorum superficialis and profundus, FF) of the right arm were recorded. Force and EMG data were amplified and recorded at 2000Hz using the Biopac MP150 system (Biopac Systems Inc., Goleta, CA) with the associated Acknowledge software. From EMG signals, the mean co-contraction index between the finger flexors and extensors was computed (Falconer and Winter, 1985), as well as the evolution of mean power frequency. The maximum force applied by each participant during the pull-up series was recorded. For the hold grip conditions (10mm, 14mm, 18mm, 22mm), the maximal force applied during pull-ups was expressed as a ratio of the MVF of the corresponding hold depth. Based on Newton's second law and using successive integration of the force recordings, the maximal power and summed mechanical work were calculated.

Results and Discussion

Results (Figure 2) showed that the climbers' performance on the large climbing hold and gym-bar were similar: there was no significant difference in the number of pull-ups, maximal force applied, maximal power, and summed mechanical work. This indicated that training with pull-ups on a gym-bar or large climbing hold is a similar exercise from the arms point of view. Nevertheless, the co-contraction index of the forearm muscles (0.64±0.13 with the large hold vs 0.43±0.15 with the gym-bar), as well as the finger-flexor muscle fatigue index (-0.005±0.0031 with the large hold vs -0.003±0.002 with the gym-bar), were significantly different between these two conditions indicating that the pull-ups were not similar from the hand and forearm point of view. On both the gym-bar and large climbing hold, the participants executed body coordination movements, such as knee/hip flexions, and uncontrolled body swings during the pull-up exercise. The differences in EMG results between the two conditions suggested that these body movements were differently compensated and/or generated on the large climbing hold compared to the gym-bar, resulting in increased forearm muscle co-contraction and fatigue with the large hold. This information is important for climbing trainers, who usually aim to train the upper-limb segments in combination to mimic the behaviour of the upper-limbs during sport-climbing. From this standpoint, doing pull-ups on a large climbing hold is clearly better than using a gym-bar.

Another notable finding of this study is the effect of hold depth on the pull-ups performed with climbing holds. A decrease in hold depth led to a considerable decrease in the number of pull-ups, maximal force applied, maximal power, and summed mechanical force. The obvious explanation is a decrease in the maximal finger force capacities resulting from the reduction in hold depth, previously observed and modelled by Amca *et al.*, (2012). During pull-ups, we observed that the maximal force applied compared to the large climbing hold was -31%, -25%, -19%, and -17% with the 10mm, 14mm, 18mm, and 22mm holds, respectively (Figure 2). Nevertheless, the maximal force applied during the pull-ups only represented 88% to 94% of the maximal finger force capacities measured during static maximal finger force contractions. These observations led to several conclusions: first, maximal finger force capacities are not fully used during pull-ups, since we observed a force-deficit, which apparently increased for the deepest hold (22mm). Second, the evolution of the maximal force applied during pull-ups according to hold depth did not reflect that of maximal finger-force capacity, since different force-deficits were observed. For trainers, these data may be useful for quantifying the loading on the fingers during pull-up training on small climbing holds.

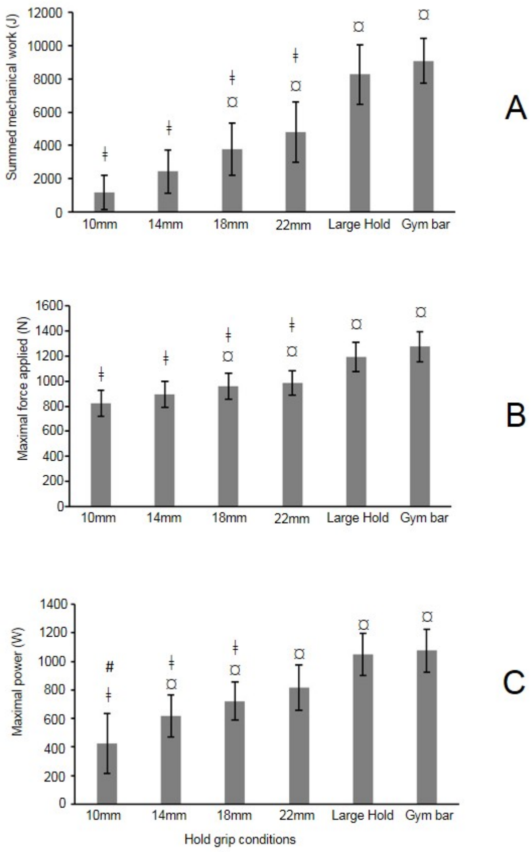

Figure 2. Mean (± SD) of the summed mechanical work (A), maximal applied force during pull-ups (B), and maximal power (C) for each grip condition. ¤ indicates significant difference (<0.05) with the 10mm hold condition. ǂ indicates significant difference with the gym-bar condition. # indicates significant difference with all other conditions.

Comparing the impact of hold depth on maximal force applied (Figure 2B) and maximal power (Figure 2C) revealed a more marked decrease for the power variable (-60%, -41%, -31%, and -23% compared to the large climbing hold for the 10mm, 14mm, 18mm, and 22mm holds, respectively). Since power is the result of maximal force applied and velocity, this revealed that the pull-ups were performed increasingly slowly as the hold depth decreased. This may be explained by the fact that it is necessary to restrict body swings and other movements when performing pull-ups on the small climbing holds, to avoid losing the grip. The participants probably thus reduced the pull-up velocity to minimize swinging and restrict body movement coordination.

The summed mechanical work (and, obviously, the associated number of pull-ups) are the most impacted parameters according to the hold size. Compared to the large climbing hold, decreases ranged from -41% with the 22mm hold to -86% with the 10mm hold (Figure 2). In addition to the explanations above (body equilibrium control, decrease in finger force capability, and force-deficit), there is also a clear forearm muscle fatigue effect, resulting from the exertion of finger forces on the holds during the entire exercise. This fatigue effect was confirmed by the evolution of the EMG MPF of the finger flexors which strongly decreased concomitantly (*e.g.* -0.02±0.02 with the 10mm hold vs -0.0069±0.0046 with the 22mm hold). Consequently, pull-ups on climbing holds also represent a good exercise for enhancing forearm fatigue resistance. Nevertheless, the deterioration in performance (maximal power and summed mechanical work) indicated that the muscles mobilizing the elbow and shoulder were less and less solicited as climbing hold depths decreased. Trainers should thus choose the depth of the holds carefully, to suit the targeted capacities and objectives of the pull-up exercise.

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