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► **To cite this version:**

Xavier Hugues, Sophie Oudar, Violaine Cahouet, Franck Quaine. Coordination of upper and lower limbs in climbing dyno movement. 2024. hal-04738064

HAL Id: hal-04738064

<https://hal.science/hal-04738064v1>

Preprint submitted on 15 Oct 2024

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Coordination of upper and lower limbs in climbing dyno movement

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Keywords: Sport Climbing, Dyno, Reaction force, Forces coordination

1. Introduction

Climbing is a specific mode of vertical quadrupedal locomotion (Noé et al., 2001) that requires the management of balancing and muscular forces optimization problems (Quaine et al., 1997b). In recent years, dynamic movements have become more and more present in the opening of boulders and routes in sport climbing competitions. During these movements, the climber generates an impulse on their supports to initiate a flight phase, enabling them to reach an otherwise inaccessible hold. This specific movement, called a dyno, involves using all four limbs on climbing holds to produce a vertical jump necessary to catch the next hold. Only a few studies have been carried out on this kind of movement. (Fuss & Niegl, 2010) showed that the jump height achieved during a dyno is a success factor. In fact, jumping higher than the hold to be reached allowed the gripping effort required when landing to be reduced. Another study (Phillips & Jensen, 2015) focused on initial hold positions and counter-movement effects, but the results obtained did not describe the behaviour of high-level climbers. Furthermore, these few studies utilize motion capture to focus on hand movements and force sensors only on the landing hold. However, how the climber coordinates his feet and hands support forces to produce the impulse and jump as high as possible remains an open question.

This abstract aims to investigate the repartition and coordination of feet and hand forces on holds during a dyno movement performed by expert climbers.

2. Methods

2.1 Participants

Seven expert climbers (age: 22.7 ± 1.1 years, height: 176.3 ± 7.6 cm, mass: 68.6 ± 8.4 kg, over 7c French route grade) participated.

2.2 Protocol

Each climber performed 3 dynos. A similar initial position was required for each subject in order to control the initial postural constraints (Quaine et al., 1997a). They were asked first, to stabilize on their four initial holds, with straight upper-limb and bent knee at

60° and then, create the impulse to jump using their four limbs in order to reach as high as possible with both hands simultaneously. The study design was approved by the Ethics Committee CERSTAPS (IRB00012476-2023-18-07-262).

2.3 Material & data analysis

A smart rock-climbing wall was used for the experiments. Four three-axis force sensors (225 Hz) were used to obtain hands (Fhands) and feet (Ffeet) support forces during dyno. Force signals were filtered using a 4th order Butterworth filter with a cutoff frequency of 40Hz and were normalized by weight. Time values were normalized to the ascending time. Fhands and Ffoot were summed to obtain the resultant force (Ftot).

Qualisys® reflective markers located on the ulnar styloid processes were used to measure vertical hands position during dyno (225 Hz). The arm-jump height was obtained by calculating the maximum vertical hands elevation in relation to its initial position on the starting hold.

3. Results and discussion

The average arm-jump height is 1167.7 ± 140.6 mm. Table 1 shows mean absolute vertical and antero-posterior forces at upper and lower limbs supports, averaged during their respective support times and expressed with respect to body weight. With a mean value of 122,4%, the feet make the greatest contribution to vertical impulse production, more than double that of the hands. However, the mean contribution to the antero-posterior impulse is fairly equivalent for upper and lower limb supports. This difference between hand and feet suggest that feet are mostly invested in vertical impulse generation while the hands focused on managing the antero-posterior centre of gravity trajectory during dyno.

Vertical		Antero-posterior	
Hands	Feet	Hands	Feet
53,7%	122,4%	38,7%	45,0%

Table 1 – Mean value of vertical and antero-posterior forces at upper and lower limbs, normalized with respect to body weight.

Figure 1 displays the time evolution of the average hands, feet and resultant forces in the vertical (A) and antero-posterior (B) directions during dyno for all participants. With regard to support holding time, the climbers' main strategy is to take off with their feet before their hands, for 6 out of the seven climbers. The mean feet take off time is at 71.8% (indicated by the orange line).

Even though vertical forces are evenly distributed under the supports at movement initiation, vertical loading under the feet increases much more than under

the hands during dyno. The maximum load on the feet is 157% of body weight, whereas it's only 84% on the hands, for a total maximum force of 226% achieved during the movement. While the feet took off, the hands were still involved in the ascension with a mean vertical force of 23% of body weight.

Concerning antero-posterior forces in Figure 1B, hands and feet loading act in opposition with a quite similar loading profile. Hands pull on holds with a maximum force of 66% of body weight while feet push on holds, resulting in negative effort values, with an absolute maximum strength value of 55%. This results in an average total antero-posterior force close to zero (5.3%). More precisely, the feet are initially predominant, causing a slight displacement of the centre of gravity away from the wall from its initial position. At 24 % of the ascent time, the total anteroposterior force reaches 0 and starts being positive, which mean that the hands are used to bring the centre of gravity closer to the wall. It is observed at upper limbs support that the climber control differently the vertical and anteroposterior force components, as the vertical force decreases while the anteroposterior force increases. This indicates that the hands play a role in modifying the horizontal trajectory and contribute less to the ascent effort.

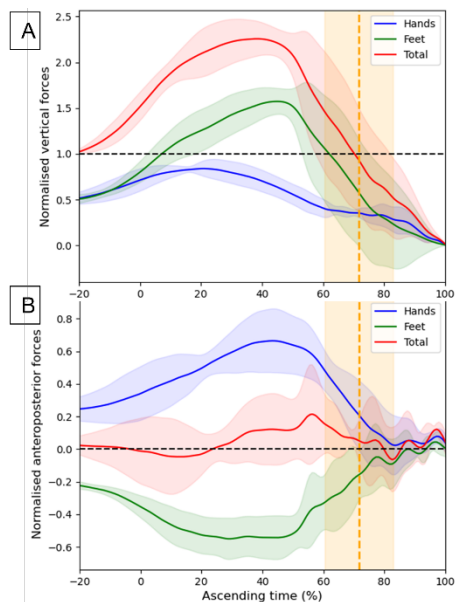


Figure 1 – Time evolution of vertical (A) and antero-posterior (B) weight normalised forces of the hands, feet and total.

4. Conclusions

The study of the forces generated at the supports during dyno execution, with expert climbers, provides a deeper understanding of this dynamic movement. It can be concluded that, even though vertical forces are evenly distributed under upper and lower limb supports at movement initiation, the feet are mostly

invested in generating vertical impulse during dyno movement.. Lastly, although the hands also contribute to vertical elevation at the very start and at the end of the movement, when the feet have lifted off, it turns out that the upper limbs support serves more to regulate the antero-posterior displacement of the centre of gravity by counteracting the recoil effect of the foot thrust. Further experiments with different initial positions should be conducted.

Funding

This study was partly funded by the ANR PPR STHP 2020 (project PerfAnalytics, ANR 20-STHP-0003). This work is supported by the French National Research Agency in the framework of the "Investissements d'avenir" program (ANR-15-IDEX-02).

Conflict of Interest Statement

None

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Received date:07/04/2024

Accepted date: 28/06/2024

Published date: XX/XX/2024

Volume: 1

Publication year: 2024