EFFECTS OF FATIGUE AND DIFFERENT CRIMP SIZES ON MUSCLE SYNERGIES DURING DEAD HANGS: A PILOT STUDY ON CLIMBERS

Juliana Exel[1], Paul Kaufmann[1], Laurenz Platzer[1], Markus Karner[1], Arthur Gáspari[2], Arnold Baca[1], and Hans Kainz[1]

Department of Sport and Human Movement Science, University of Vienna, Vienna, Austria[1]
Brazilian Sport Climbing Association, Brazil[2]

The aim of this pilot study was to investigate the impact of different hold sizes on the motor control of upper body muscles during intermittent dead hangs. Four elite-level climbers (3 females, 1 male, 25.5 ± 6.8 years, 166.0 ± 7.8 cm height, 59.0 ± 8.8 kg weight, and 21.0 ± 1.4 IRCRA scale climbing grade ability) performed body-weight intermittent isometric dead hangs (7:3 s work-to-relief ratio) until failure, using a half-crimp position, onto edges of 10- and 30-mm. Muscle activations of upper limb muscles were recorded with surface electromyography electrodes and then used to calculate muscle synergies and forces were measured on an instrumented hang board. Results showed that two synergies were mainly used during the intermittent test: Synergy 1 with a higher contribution of the hand muscles, and Synergy 2 with higher contributions of the arm and trunk muscles. A cross-correlation analysis showed high correlations of both synergies between each crimp size (Synergy 1 and 2 at 10 and 30 mm had r = 0.98 and r = 0.89, respectively). A detailed correlation analysis throughout the whole time series indicated close to fatigue, Synergy 1 decreases activation while Synergy 2 increases, especially in the second half of the dead hang cycle. Our findings provide a nuanced understanding of upper body muscle involvement in intermittent dead hangs, informing future research on motor control and fatigue in climbing-related activities.

KEYWORDS: climbing, EMG, motor control, strength training.

INTRODUCTION: Climbing routes and boulder problems often present, ether naturally or designed by the route setter, a variety of holds sizes and shapes to challenge climbers' skill abilities in griping and supporting their body weight while ascending. Isometric finger strength and endurance are key for climbing performance (Saul et al., 2019), and overhead training tasks as dead hangs are the most popular to develop such capacities (López-Rivera & González-Badillo, 2019). It's known that inability to maintain work impact postural adjustments of climbers while sustaining max time open crimp hangs, demanding changes in coordinative patterns of the upper body joint kinematics and muscle activations (Exel et al., 2023). Thus, understanding how the nervous system organizes the recruitment of muscle groups into functional unities or synergies to perform a task plays a significant role in assessing strength capacity (Pham et al., 2023). It enables a comprehensive view on movement efficiency, which, in turn, allows for appropriate training load planning, injury prevention, and enhanced performance. The aim of the present study was to characterise motor control-related changes in specific gripping techniques involved in intermittent isometric finger contractions during dead hangs.

METHODS: Four elite-level climbers (3 females, 1 male, 25.5 ± 6.8 years, 166.0 ± 7.8 cm height, 59.0 ± 8.8 kg weight, and 21.0 ± 1.4 IRCRA scale climbing grade ability), experienced in using a hang board, and with no recent history of upper body injuries participated in the experiment. Participants were instructed to perform body-weight intermittent isometric dead hangs (Fig. 1 C) with a work-to-relief ratio of 7:3 s until failure, using a half-crimp position, onto holds of 10 and 30 mm, with 20 min rest in between. Forces applied during the finger hangings in the vertical and medial-lateral directions (Fig 1. B) were measured using force sensors mounted on the hang board (Fig. 1 A). These 2D sensors were based on 4 HBM strain gauges for each direction, as Wheatstone bridge circuit, mounted on a National Instruments cDAQ-

9174 (Maffiodo et al., 2020). The force sensor was synchronized with the electromyography system at a sampling frequency of 1000 Hz, and filtered with a 4th-order zero-lag low-pass filter with cut-off frequency of 4 Hz. Electromyographic signals (EMG) from the flexor digitorium superficialis (L/R fingFlex), extensor digitorium (L/R fingEx) biceps brachii—long head (L/R bicep), triceps–long head (L/R tricep), and latissimus dorsi (L/R Lat) were recorded from both left and right limbs using a wireless system (Cometa®, Milan, Italy) at a sampling rate of 2000 Hz. The placement of surface electrodes followed the SENIAM guidelines (SENIAM, 2009) for all muscles, except for the fingFlex, which was placed according to Vigouroux et al. (2015). The start and end of each bout during the intermittent exercise was defined by the vertical-force data, and we considered the middle 60% of the bouts for all furtheranalysis. The recorded EMG-signals were band-pass filtered (4th-order zero-lag Butterworth filter) with cut-off frequencies between 3 and 300 Hz, rectified using the Hilbert-transformation and low-pass filtered (4th-order zero-lag Butterworth filter) at 6 Hz. Processed signals of all bouts of each participant were concatenated and amplitude normalized to the peak EMG activity of each muscle (Turpin et al., 2021). One to five muscle synergies were extracted via non-negative-matrix-factorization (Soomro et al., 2018). Sparse initialization was used due to the high temporal overlap of the activation coefficients – which we expected due to the isometric nature of the task. To avoid the algorithm getting stuck in local minima, the factorization was repeated 30 times, and outputs with the highest total variance accounted for were further analysed. Knee-point analyses of the total variance accounted for curve yielded that two synergies were sufficient to represents motor control of the intermittent task. K-means clustering (based on correlation) was used to order the synergies across participants. The activation coefficients and force outcomes from the left and right holds were averaged and time-normalized for further analysis. A zero-lag cross-correlation analysis was applied to evaluate similarity between the different crimp sizes and synergies time series. We also used a moving correlation coefficient at each 10% of the dead hang cycle to quantify the degree of linear relationship between these time series.

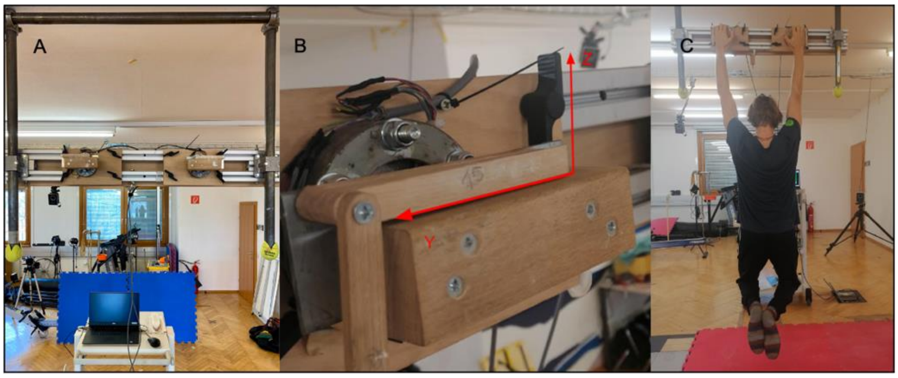

Figure 1. (A) Instrumented hang board used in the study. The force sensors were placed in separate hand holds, with height and width being adjusted according to participant's individual anthropometry. (B) Detail on the setting of the different crimp sizes on the hang board-hand hold and the direction of the forces measured. (C) Posture adopted during the maximum time dead hangs exercise.

RESULTS: On average, participants working time was 35 ± 21 s at 10 mm and 126 ± 63 s at 30 mm. The distribution of the muscle weightings across the 2 synergies found for the dataset are represented in Fig 2 (a-b). Synergy 1 showed a higher contribution of the hand muscles whereas Synergy 2 presented higher contributions of the arm and trunk muscles. We found higher levels of activation of Synergy 1 at 30 mm when compared to 10 mm, with a drop after 60% of the dead hang cycle, as in Figure 2 (c) and (e). However, at both hold sizes Synergy 1 decreases towards the end of the exercise. Synergy 2 shows an increase of activation during the exercise cycle, and seems to present a higher activation level at 10 mm in a visual comparison to 30 mm. The cross-correlation results showed very high correlation of both synergies between each hold size. Synergy 1 at 10 and 30 mm had r = 0.98 and Synergy 2 at 10 and 30 mm had r = 0.89. A detailed correlation analysis throughout the whole time series indicated that both synergies behave differently, with negative coefficient values, at the first half of the cycle when both crimp sizes were compared, opposite to the second half of the dead hang cycle.

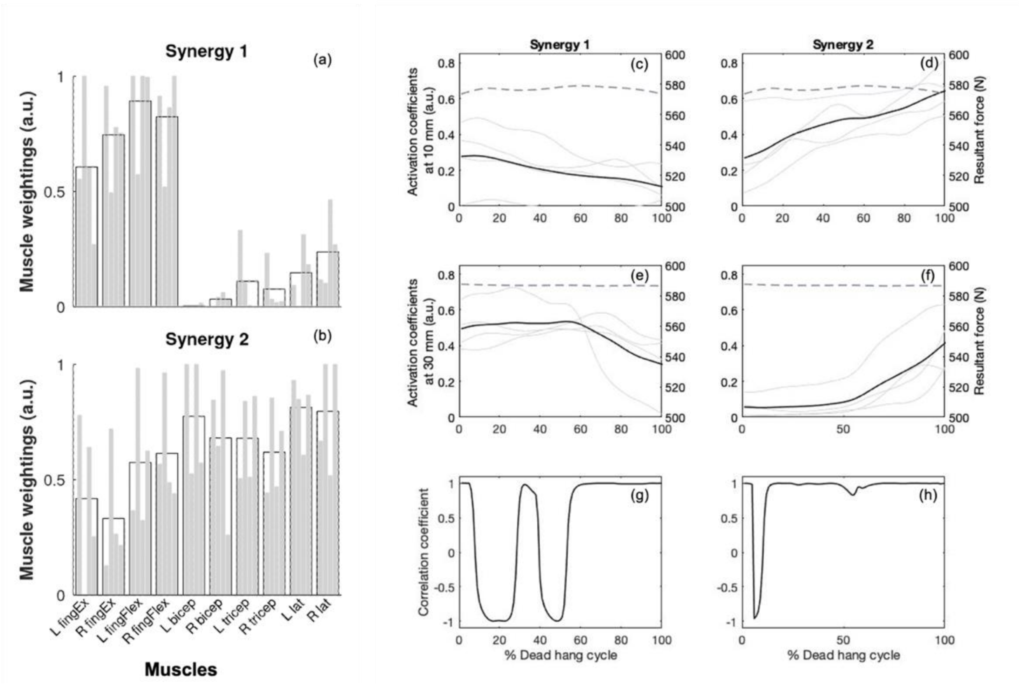

Figure 2. Left panel: Muscles weightings within synergies for the muscles analysed in the study. Synergy 1 contains mostly hand muscles and synergy 2 had high contributions of the arm and trunk muscles). Right panel: (c – f) activation coefficients from Synergy 1 and 2 during half-crimp intermittent dead hangs performed at 10 and 30 mm vs. dead hang cycle (0% = beginning of the exercise, 100% = last intermittent bout). The thick solid black line is the mean activation coefficients from 4 subjects during the task (thin solid grey lines). The dashed grey line is the mean resultant force, representing the outcomes of the task. In (g – h) it is represented a moving correlation at each 10% of the cycle of the synergies found for 10 and 30 mm intermittent dead hangs.

DISCUSSION: The objective of this pilot study was to investigate the impact of different hold sizes and fatigue on the motor control of upper body muscles during intermittent dead hangs. Our findings reveal that these muscles can be categorized into two primary functional units. One primarily comprises hand muscles (Synergy 1 with finger flexors and extensors), while the other mainly involves arm and trunk muscles (Synergy 2 with biceps brachii, triceps brachii, and latissimus dorsi). These synergies seem to influence intermittent dead hangs differently depending on the size of the hold that was used. Synergy 1 demonstrates higher activation throughout the task cycle when climbers hang from a larger hold compared to a smaller one. Nevertheless, for both hold sizes, particularly beyond the midpoint of the cycle, synergy activation levels diminish, consistent with expectations as the exercise approaches the point of failure. Conversely, Synergy 2 showed higher activation levels during intermittent tasks with smaller holds compared to larger ones. Additionally, at both hold sizes, it registers an increase in activation levels towards the point of failure. Previous studies have elucidated that dead hangs, executed on a 22 mm edge in sustained isometric contraction, induce postural adjustments in the coordinative patterns of upper body joint kinematics and muscle synergies in a proximal-to-distal manner (Exel et al., 2023). This phenomenon facilitates a balanced body position and efficient gripping, thereby compensating for neuromechanical impairments resulting from fatigue. Our results enlarge the understanding of how the nervous system modulates the organization of upper body muscle activity during overhead tasks, by delineating the compensation strategies in response to fatigue when the task performed with markedly different hold sizes. Larger holds appear to invoke greater involvement of hand muscles, demanding reduced activation of arm and trunk muscles in the initial phase of the task. These changes in the latter half of the task reflects the declining force-generating capacity in hand muscles being compensated by an increased co-activation of trunk and arm muscles to sustain essential functions during dead hangs. Smaller holds are harder to hang on (number of bouts performed differed substantially, as an example), and necessitate a highly complex motor control from the outset. Both synergies exhibit comparable activation levels at the task's start, revealing the integral role of the entire upper body in task execution regardless of fatigue status. Over the task cycle, Synergy 1 gradually decreases its activation, seemingly relying heavily on Synergy 2, which increases up to 3 times its initial value at the point of failure.

CONCLUSION: This pilot study illustrates the impact of hold sizes and fatigue on the upper motor control in intermittent dead hangs, revealing distinct patterns in the activation of upper body muscles. Two primary synergies emerge: Synergy 1, predominantly comprising hand muscles, and Synergy 2, involving arm and trunk muscles. Larger holds seem to have a greater reliance on the hand muscles initially, with a subsequent shift towards increased engagement of arm and trunk as fatigue sets in. Conversely, smaller holds demand intricate motor control from the outset, with both synergies playing crucial roles. Hand co-activation levels gradually decreases, while the co-activation of arm and trunk muscles intensifies, especially nearing task failure. These findings offer valuable insights into how the nervous system adapts muscle activity organization during overhead tasks of varying hold sizes, giving insights on compensation strategies employed in response to fatigue. Our findings provide a nuanced understanding of upper body muscle involvement in intermittent dead hangs, informing future research on motor control and fatigue in climbing-related activities.

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