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ORIGINAL

DIFFERENCES IN MOTOR PATTERNS OF CLIMBERS WITH THE DYNO TECHNIQUE

DIFERENCIAS EN LOS PATRONES MOTORES DEL GESTO DE LANZAMIENTO EN ESCALADORES

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ABSTRACT

The aim of the present study was to describe and compare the motor patterns of climbers with different skill levels when using the dyno technique. The sample of participants was 10 climbers, 5 high skill climbers and 5 low skill climbers. Kinematic variables of position, velocity and acceleration of different body segments were measured. A 23-point anatomical model, together with the IBV KINESCAN software, were used to digitize the movement patterns. A MANOVA showed differences according to the skill level in some kinematic variables. Specifically, the skilled climbers achieved higher velocity of the centre of mass, hip and elbows during the impulse phase. Results suggest that the skill in the dyno technique allowed climbers to generate faster movements in certain body segments in order to reach a handhold positioned at a higher height than the starting position.

KEY WORDS: Motor Pattern, Climbing, Biomechanics, Kinetics, Sports level.

RESUMEN

El objetivo del presente estudio fue describir y comparar el patrón de movimiento de escaladores de diferente Nivel deportivo durante la técnica de lanzamiento. La muestra estuvo compuesta por 10 escaladores, 5 de alto nivel y 5 de bajo nivel. Se midieron variables cinemáticas de posición, velocidad y aceleración de diferentes segmentos corporales. Se utilizó un modelo anatómico de 23 puntos y el software KINESCAN del IBV para digitalizar el patrón de movimiento. El MANOVA realizado mostró diferencias según Nivel deportivo en ciertas variables cinemáticas. Específicamente, el grupo de mayor nivel obtuvo mayor velocidad del centro de masas, cadera y codos durante la fase de impulso. Los resultados obtenidos sugieren que la destreza en la técnica permitió generar movimientos más rápidos en determinados segmentos corporales a fin de alcanzar una presa del rocódromo dispuesta a una altura superior a la posición inicial del escalador.

PALABRAS CLAVE: Patrón motor, Escalada, Biomecánica, Cinemática, Nivel deportivo.

1 INTRODUCTION

Climbing is a sport discipline that exerts a high muscular-skeletal demand as the climber must support body mass influenced by a gravitational load (i.e., body weight). The climber has to coordinate body segments and generate optimal positions according to the characteristics of the route in order to avoid slips and falls. This demand on the motor system differs greatly from normal human locomotion due to the need for coordination between upper and lower limbs, and trunk in moving along a vertical trajectory. Therefore, the mechanical work in climbing differs greatly from typical daily actions (Russell, Zirker, & Blemker, 2012). In addition, Sibella, Frosio, Schena and Borghese (2007) concluded that climbing, unlike human bipedal locomotion, is a type of quadrupedal locomotion in the vertical plane that requires a minimum support of one limb (or more) in order to offset gravitational forces and prevent falling.

Several studies have analysed the physiological characteristics of sport climbing (e.g., lactate concentration and heart rate; see Sheel, 2004 and Watts, 2004), and the different physiological responses to different types of routes, vertical and horizontal (de Geus, Villanueva, & Meeusen, 2006). For example, Giles, Rhodes and Tauton (2006) concluded that a high level of strength and endurance of muscles in fingers and shoulders, together with the ability to tolerate and eliminate lactates, could explain the success of rock climbing. España-Romero et al. (2009) concluded, after an analysis of the existing literature, that low body weight and body fat percentage together with high finger strength and endurance were the anthropometric and physiological variables that best characterized expert climbers. In this line, Fryer, Giles, Garrido-Palomino, de la O Puerta and España-Romero (2018) recommended training of the general aerobic capacity and of the forearm musculature as the index of oxidative capacity of the forearms or the peak of VO_2max consumption predicted rock climbing performance.

Another group of studies concluded that the crucial factor in climbing performance is the maximum finger strength (Baláš, Pecha, Martin, & Cochrane, 2012; López & González-Badillo, 2012; Mermier, Janot, Parker, & Swan, 2000; Úbeda, 2004; Vigouroux, Quaine, Labarre-Vila, & Moutet, 2006; Watts, 2004). Specifically, there are studies that have analysed: i) the mechanical load of the fingers in different climbers and grips (Lopez-Rivera & Gonzalez-Badillo, 2012; Morenas, Luis, Leyton, Gómez-Valadés, & Gómez, 2013), ii) the relevance of friction between the hand and the grip (Konstantin & Niegl, 2012), iii) the electrical activity of the muscles in different climbing actions (Vigouroux & Quaine, 2006), and iv), the resistance of the flexor muscles of the fingers (Ramírez, Lancho, Poblador, & Lancho, 2018). Additionally, other studies have described the three-dimensional forces obtained during postural changes through the deformation of three-dimensional load cells, allowing the quantification of forces applied at each hand hold. The simulation of these postural changes during the climbing movement have supported analyses of the vertical and horizontal forces applied in different grips (Frederic, Quaine, & Martin, 2001; Morenas et al., 2013). Piezoelectric transducers have been used to measure more specific climbing techniques (e.g., the throwing technique), recording the force applied on both the upward and downward trajectory hand holds (Fuss & Niegl, 2010).

Recently, Saul, Steinmetz, Lehmann and Schilling (2019) carried out a systematic review of climbing studies in order to find out which factors contributed to climbing performance. They concluded that high level climbers showed high strength and endurance in fingers, as well as a high level of motor and postural control. At a physiological level, their analysis highlighted the strength-weight ratio of their finger flexors, aerobic capacity, vasodilation and re-oxygenation. At an anthropometric level, expert climbers showed long fingers, large forearm volume and low body fat percentage. The most effective type of training to achieve good results in climbing were exercises with small edges to strengthen the fingers, eccentric-concentric work, as well as continuous training with active recovery phases.

To quantify the mechanics used in climbing techniques, different biomechanical models must be used to analyse these complex human movements. For example, there are some recent models as following: i) the *inverse dynamics model* that measures the differences in angles and torques to quantify the mechanical work performed in climbing movements; ii) the *musculoskeletal model* used to evaluate how kinematic strategies and ranges of motion affect the muscle in its ability to generate force, and iii) the *forward dynamic model* developed to understand the energy expenditure of different strategies in sport climbing (Russell et al., 2012). there have been very few studies that have investigated the contribution of skill level on the organization of movement in sport climbing. One exception, by Seifert et al. (2014) found that higher level climbers showed better coordination of the upper and lower extremities due to an efficient use of the information provided by the properties of the ice climbing route.

But there is a need for more of this nature to provide clear guidance on interventions to increase sport climbing skills and analyse requisite perceptual and motor adaptations that help climbers enhance performance through practice and implementation of different learning strategies (Orth, Davids, & Seifert, 2016). In this line, the objective of this study was to analyse and compare the kinematics of the dyno technique in a sample of climbers of different skill levels, using a 3D photogrammetry system (KINESCAN software from the Biomechanical Institute of Valencia, IBV, 2011). The kinematic data collected and analysed during climbing performance were based on recommendations of other studies (Cha, Lee, Heo, Shin, Son, & Kim, 2015; Sibella et al., 2007). For example: i) elbow and knee joint angle (left and right); ii) hip position (left and right) in the x, y, z components; iii) elbow and knee angular acceleration (left and right); iv) elbow and knee angular velocity (left and right); v) hip acceleration and velocity in the x, y, z components (left and right); and vi) acceleration, velocity and position of the centre of mass (COM) in the x, y, z components.

2 METHODS

2.1 PARTICIPANTS

The sample of participants included 10 male climbers (M age = 27.40 yrs; SD = 12.12). The climbers with the highest skill level (n=5) were part of the regional sport climbing team, with competitive experience of performance in national and international championships. On the other hand, the low skilled group (n=5) were climbers that have practised climbing at a recreational level. Both groups accumulated more than eight years of climbing experience. The division of the climbers into the groups was based on the French scale or maximum grade. This scale ranked the performance level of climbers according to the most difficult route that they have been able to climb. From this scale, the expertise of the climbers was divided into two levels: low level (IV-6c+) and high level (8a-9b). Skilled climbers obtained a high-performance level (i.e., minimum of 4) and the non-skilled climbers achieved a low level (i.e., maximum of 2.25) with the standardized conversion table of climbing capacity (Watts, Martín, & Durtschi, 1993).

The criteria to recruit participants was through a non-probability sampling selection based on a convenience sampling (Salkind, 1999) since the climbers of each group would satisfy some requirements according to the skill level and sports experience. Specifically, the effect of experience was the same between groups (i.e., all participants were experienced climbers with more than eight years of experience) in order to avoid its influence on the possible relationship between the skill level and kinematic variables analysed. In addition, the low-skill level group was required to perform a low performance on the maximum scale, and the skilled group performs high scores in this scale.

Each participant was informed of the aims of the study and gave written informed consent to participate in the experimental process. No information was given about the hypotheses tested. The research was conducted in accordance with the principles of experimentation on human beings established by the University's Commission of Bioethics and Biosafety, and the Declaration of Helsinki (2013).

2.2 INSTRUMENTATION

A system of two cameras with a sampling frequency of 60 Hz was used for the kinematic analysis of the climber's movements. A reference system of a cube with dimensions 2 m x 2 m x 2 m (x: abscissa, y: ordinate, z: elevation) was used for space calibration (see Figure 1).

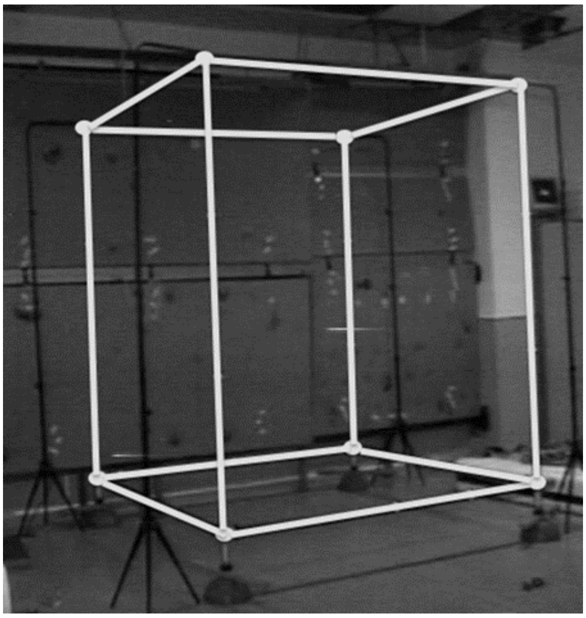

Figure 1. Reference system used for space calibration in the artificial climbing wall used in the research

The KINESCAN software of the Biomechanical Institute of Valencia (IBV) was used to record images of climbers for later digitalization and processing. The climbing task was carried out on an indoor climbing wall facility measuring 4m wide by 3m high, with two hand holds and two footholds, placed at the same height, and a target hold. The hand holds were placed at a distance of 40 cm between them and at a distance of 100 cm from the foot holds. The distance between the starting and the target hand holds was 100 cm (see Figure 2).

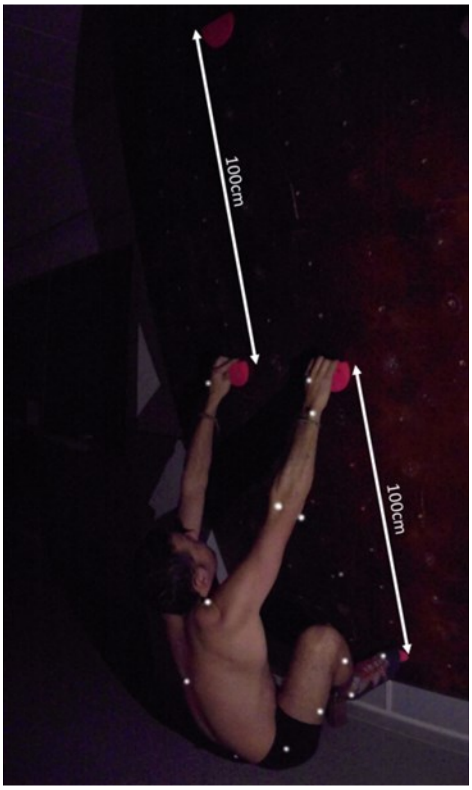

Figure 2. Participant with markers and configuration of the climbing wall for the research.

Finally, a measurement tape and an isometric dynamometer (Interface, SSM-AJ-5000N) were used to test the battery of anthropometric features (i.e., height and arm span) and physical features of participants (i.e., general and specific finger strength; leg isometric strength; shoulder and leg flexibility).

2.3 VARIABLES

The independent variable of the study was the skill level of climbers (Level 1: Low skill level, Level 2: High skill level), according to the structuring of skill level proposed by the French scale. The dependent variables were as follows:

- Angle of the elbow and knee joint (left and right) in º.
- Position of the hip (left and right) in x, y, z components in cm.
- Angular acceleration of the elbow and knee (left and right) in rad/ s².
- Angular velocity of the elbow and knee (left and right) in rad/s (ω).
- Acceleration and hip velocity in x, y, z (left and right) in m/s² and m/s respectively.
- Acceleration, velocity, and position of the mas centre (COM) in x, y, z components, as well as the module in m/s² and m/s respectively.
- Time (s) taken by each group to complete each of the 4 phases into which the motion pattern analysis was divided.

Specifically, the analysis of the kinematic variables was divided into 4 phases in order to describe more precisely the movements performed by the climber (Figure 3). These phases were: i) Phase 1 (T1) from the moment that the participant lifted the back foot off the ground, to the moment that he put it on the foothold; ii) Phase 2 (T2) from the moment that the participant put his foot on the foothold, and began to extend his elbow to the last point at which he began to initiate elbow flexion; iii) Phase 3 (T3) from the moment that the participant began to flex his elbow to the moment that he released one of the two hand holds; iv) Phase 4 (T4) from the moment he released one of the hand holds to the moment that he reached to the target hold. Also, the anthropometric variables of height and arm span (cm) were measured, as well as the physical variables of general and specific strength of the fingers in KgF of compression exerted, and the isometric force of the quadriceps at 90º in N. According to the flexibility variables, the flexibility of the shoulder and leg joints was measured (cm).

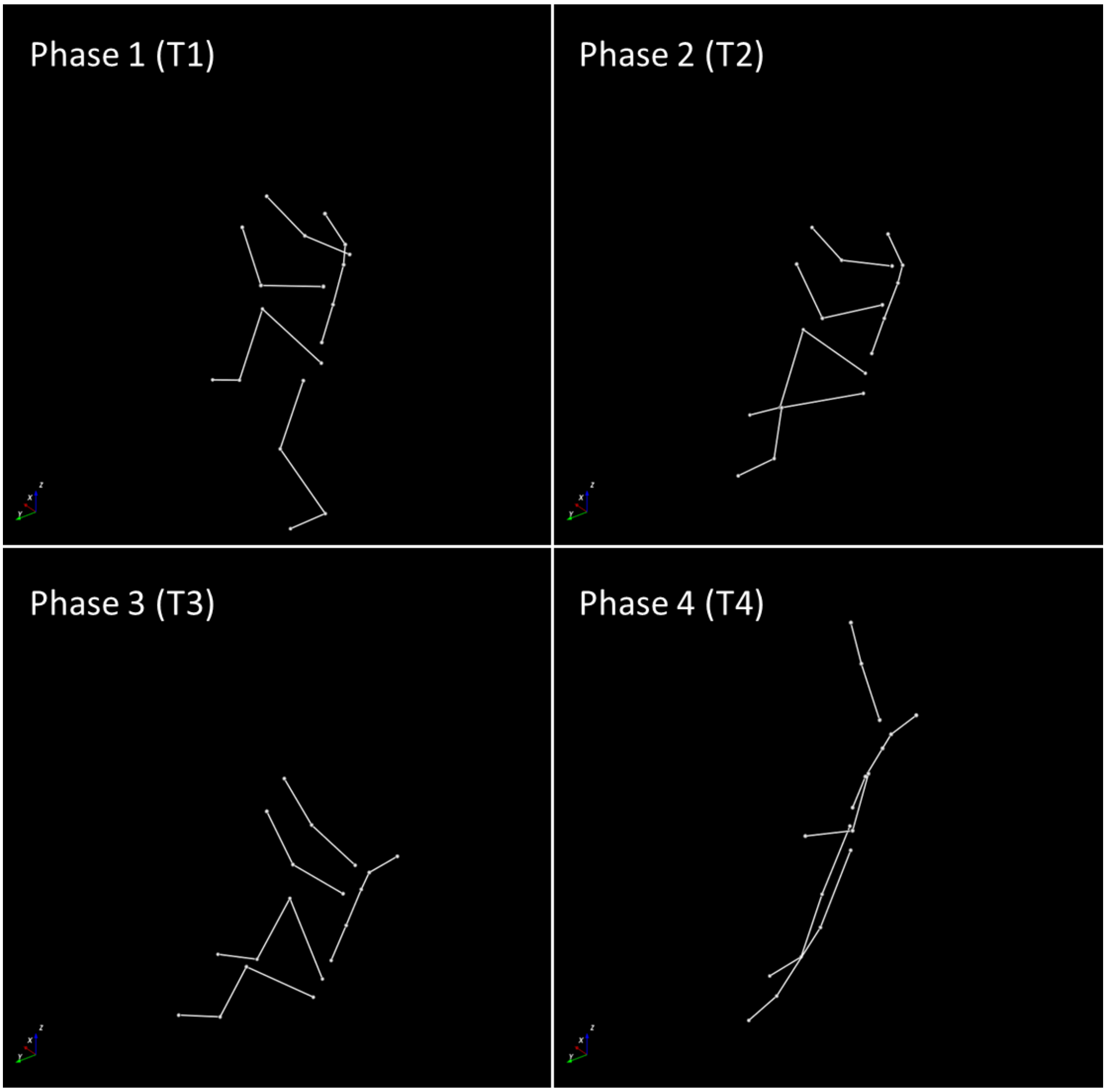

Figure 3. Phase division of the rock dyno technique for kinematic analysis.

2.4 PROCEDURE

Before the beginning of the measurements in the laboratory, the three-dimensional (3D) cube was assembled to act as a reference system for the climbers' movements in space (x, y, z axes). Once the cube was calibrated, it was removed in order to proceed with the climbing movement recordings.

Together with the calibration cube, 23 reflective markers (15 mm diameter) were attached to the skin on the anatomical landmarks of the model (Figure 2). Two spotlights were also used to illuminate the markers and facilitate their identification in the recording.

On the day of the measurements, the participants first performed the anthropometric tests and next the different performance tests. The general grip strength test (i.e., the manual gripping strength) was performed by the climber in an upright position, straight elbow and standing up. The specific grip strength test was performed by supporting the forearm and fixing the elbow beforehand, according to the methods used by Baláš et al. (2014) and Michailov et al. (2018). From this position, the climber held a grip by exerting flexion force with the fingers. The isometric force generated by the quadriceps at 90º in N was also recorded using an isometric dynamometer. With regard to flexibility variables, the flexibility of the lower limb was measured with a front split test.

The research task consisted of performing the DYNO technique characterized by a movement in which, in order to reach the next hand hold, the climber must organise a vertical action. In this specific action, it is mandatory for the climber to release the foot grip while keeping only a hand grip (generally for small climbers) or only to release a hand grip (generally for tall or medium height climbers). Specifically, participants had to perform an explosive upward movement (i.e., on the z-axis), releasing one of their hands to reach the target hand hold located 100 cm above the starting position. In general, the joints involved in this movement are the ankle, knee, hip, shoulder-humeral, elbow, wrist and the different joints of the hand.

All the climbers were video recorded executing the movement with two cameras located on each side of the participant at a 45º angulation. Participants knew which was the starting and target hold, but the position or type of grip to be performed was not specified in order to provoke freedom of movements in the execution of the technique. Once actions of all participants were recorded, the analysis was carried out with the KINESCAN software, digitizing 23 anatomical markers for the reconstruction of the 3D model, according to Leva's model (1996). Once the digitization of all participants was accomplished, the kinematic data were retrieved, and divided into the 4 phases of the dyno technique (as previously described in Figure 3) for analyses purposes.

2.5 STATISTICAL ANALYSIS

First, the Kolmogorov-Smirnov test was carried out to address whether the data were normally distributed all the kinematic variables. The results showed a normal distribution of data. Next, parametric analyses were performed to test the influence of skill level on dependent variables. Specifically, the differences of the mean values of selected variables were analysed according to the skill level of the climbers with a multivariate analysis of variance (MANOVA) test. An Alpha level of $p < .05$ was set, and the statistic ηp^2 was used to assess the magnitude of the effect that the independent variable would have on the study variables. The IBM SPSS Statistics 25 software was used to perform the statistical analyses.

3 RESULTS

The descriptive statistics displayed similar values in participants for both anthropometric and physical variables. The MANOVA showed no significant differences between the groups of climbers (see Table 1).

Table 1. *Set of anthropometric and physical variables (strength and flexibility) carried out to the climbers.*

	High Level Group	*Low Level Group*
	M (±SD)	M (±SD)
Height	168 cm (16.14)	172 cm (12.61)
Arm_Spam	172.80 cm (13.60)	175.20 cm (6.76)
GGrip_RHand	40.80 kgF (14,48)	44.40 kgF (10.87)
GGrip_LHand	40.20 kgF (11.98)	41.80 kgF (11.49)
SGrip_RHand	41.40 kgF (12.44)	32.60 kgF (7.30)
SGrip_LHand	42.00 kgF (13.28)	33.40 kgF (6.98)
Flex_Hip	120.80º (12.11)	118.80º (4.38)

Legend: GGrip=General Grip Strength; SGrip= Specific Grip Strength; Flex_Hip= Hip Flexibility.

However, there were differences in the mean values of some kinematic variables of position, speed and angular velocity, acceleration and angular acceleration in certain body segments (see Figure 4).

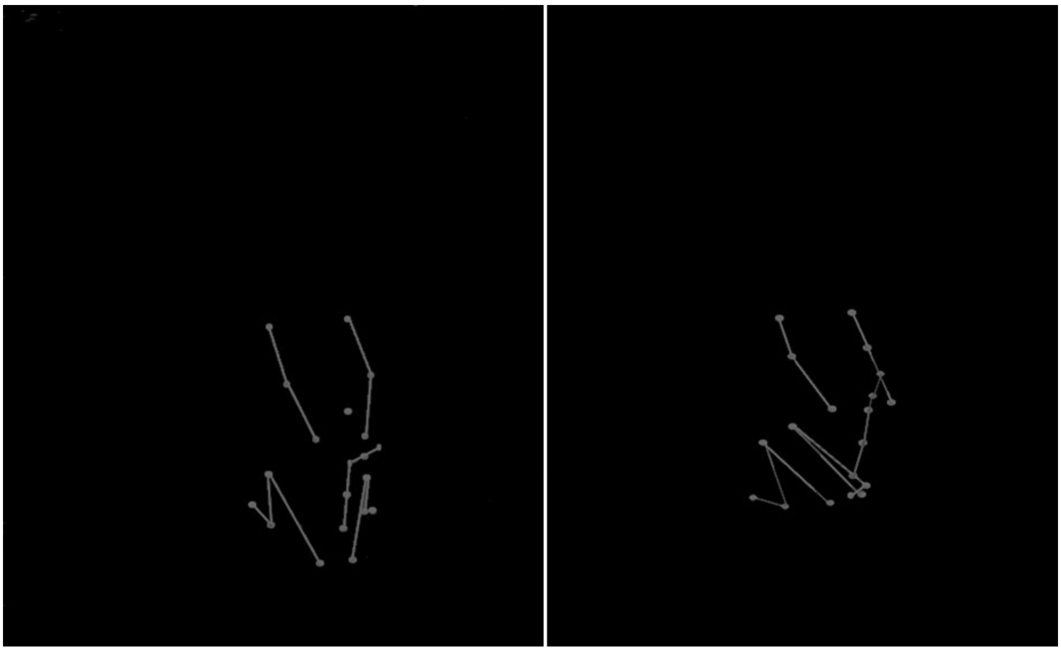

Figure 4. Example of a digitized trial with a high-skill climber (left) and a low -skill climber (right) in the starting frame retrieved from the phase 3 of the analysis.

These differences were found in the body segments of the hip and elbow, as well as the centre of mass. All these differences occurred during phase 3 of the analysis and in the z-axis (see Table 2).

Table 2. Set of kinematic variables revealing differences according to the skill level of climbers, phase and axis of analysis.

	High Level Group	*Low Level Group*
	M (± DS)	M (± DS)
M_ ang_vel_Relbow_3	190 rad/ s (17.49)	152.49 rad/ s (17.71)
M_ ang_vel_Lelbow_3	178.86 rad/ s (23.20)	132.63 rad/ s (15.03)
M_vel_Rhip_z3	1.06 m/s (.06)	.78 m/s (.09)
M_vel_Lhip_z3	1.06 m/s (.07)	.79 m/s (.08)
M_vel_COM_z3	.84 m/s (.11)	.67 m/s (.04)
M_vel_COM_total_3	.97 m/s (.12)	.80 m/s (.03)

Legend: M=Mean; ang=angular; vel=velocity; COM= mass centre.

The MANOVA showed differences between high skilled and low skilled group for the following kinematic variables: i) velocity on the right ($F(1,1) = 31.35$; $p < .001$; $\eta p^2 = .79$) and left hip velocity ($F(1,1) = 28.53$; $p < .001$; $\eta p^2 = .78$); ii) angular velocity on the right ($F(1,1) = 11.34$; $p < .05$; $\eta p^2 = .58$) and left elbow ($F(1,1) = 13.97$; $p < .01$; $\eta p^2 = .63$); and iii) velocity of the mass centre ($F(1,1) = 7.07$; $p < .05$; $\eta p^2 = .54$) and its velocity module ($F(1,1) = 6.34$; $p < .05$; $\eta p^2 = .51$).

4 DISCUSSION

The objective of this study was to describe and compare the movement patterns of two groups of climbers with different skill levels performing the climbing dyno technique. The analyses showed significant differences in kinematics variables of some body segments according to the climbing skill of participants. Specifically, high-level climbers achieved higher velocities in elbows, hips, and mass centre during phase 3 and z-axis of movement compared to the low-level climbers. In all these comparisons between groups, the effect size (ηp^2) was higher than .50 which means that the differences found are explained, at least in a percentage of 50%, by the effect of their different climbing skill level.

These results are aligned with findings of Fuss and Niegl (2010) who concluded that, to successfully perform the two-handed dyno technique in climbing, it is necessary to generate a high take off velocity to achieve an upper hold. Our findings are also aligned with data from previous studies that have revealed skill-based differences in movement kinematics skill level of climbers (Russell et al., 2012; Seifert et al., 2014). To exemplify, Seifert et al. (2013) concluded that expert climbers showed greater variability of movement compared to counterparts of lower skill levels in order to improve their adaptation to the climbing route and, in achieving performance outcomes in climbing.

It is important to note that the sample of climbers showed no differences in height, arm span, finger strength, or leg and shoulder flexibility. Therefore, physical variables were not predictive of differences between groups of climbers at a kinematic level. No differences were also found in specific finger strength or in the temporal duration of movement phases. These anthropometric data suggest that differences in kinematics revealed a more efficient reorganization of motor system degrees of freedom in movement patterns to the properties of the climbing route by the high skilled climbers (Davids, Button, & Bennett, 2008), due to a better coupling between information from the climbing wall (i.e., features and distances of and/or between holds) and specific motor actions related to the task target (Orth et al., 2016). In this vein, the skilled climbers were able to generate a movement patterns which were more functionally adapted to the objective of the task (e.g., generating a higher speed of hip and centre of mass, displacing vertically during the swing phase). This more efficient motor behaviour with respect to the conditions of the climbing route has been previously observed in experienced climbers when they modified their vertical impulse force, with regards to the grip technique and depth of the holds (Amca, Vigouroux, Arıtan, & Berton, 2012).

The characterization of movement patterns in high skill level climbers is crucial to reveal which kinematic variables differentiate their performance from other climbers with lower skill levels. This biomechanical information could help coaches to better design training sessions for novice climbers, and therefore, optimize their learning processes. In future, it would be interesting to deepen the analysis of kinematic variables in the time scale (e.g., What is the course of the acceleration of the centre of mass? Would this acceleration profile be related to a harmonic or stochastic development?). Finally, it would be interesting to compare kinetic patterns of movement in climbers of different skills in order to characterize the mechanical impulses involved in the production of movements. In this line, an intra- and inter-muscular analysis, using electromyographic technology, would help to describe the muscular intervention used in neuromuscular control, both in groups of novice and expert climbers, and in specific conditions, for example when fatigued (Limonta, et al., 2016; Vigouroux & Quaine, 2006).

5 CONCLUSIONS

The high and low skill groups of climbers showed kinematic differences in the movement pattern of the dyno technique. These differences were found for the elbow and hip joints, and also for the centre of mass. Specifically, compared to low skilled counterparts, the skilled climbers were able to generate higher velocity of movement in the right and left elbow, right and left hip, and mass centre during the swing phase (phase 3) and vertically (z-axis) for the fulfilment of task goals.

REFERENCES

Amca, A.M., Vigouroux, L., Arıtan, S., & Berton, E. (2012). Effect of hold depth and grip technique on maximal finger forces in rock climbing. *Journal of Sports Sciences, 30*(7), 669- 677.

Baláš, J., Pecha, O., Martin, A. J., & Cochrane, D. (2012). Hand-arm strength and endurance as predictors of climbing performance. *European Journal of Sport Science, 12*(1), 16–25.

Baláš, J., Panáčková, M., Kodejška, J., Cochrane, D. J., & Martin, A. J. (2014). The role of arm position during finger flexor strength measurement in sport climbers. *International Journal of Performance Analysis in Sport, 14*(2), 345–354.

Cha, K., Lee, E. Y., Heo, M. H., Shin, K. C., Son, J., & Kim, D. (2015). Analysis of climbing postures and movements in sport climbing for realistic 3D climbing animations. In A. Subic, F. K. Fuss, F. Alam, T. Y. Pang, & M. Takla (Eds.), *Impact of Technology on Sport VI' 7th Asia-Pacific Congress on Sports Technology*, Vol. 112, 52–57.

Cordier, P., Dietrich, G., & Pailhous, J. (1996). Harmonic analysis of a complex motor behaviour. *Human Movement Science, 15*, 789–807.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: A constraints-led approach*. Champaign, Illinois: Human Kinetics.

de Geus, B., Villanueva, S., & Meeusen, R. (2006). Influence of climbing style on physiological responses during indoor rock climbing on routes with the same difficulty. *European Journal Applied Physiology*, *98*, 489-496.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanovs segment inertia parameters. *Journal of Biomechanics*, *29*(9), 1223-1230.

España-Romero, V., Artero, E. G., Ortega, F. B., Jiménez-Pavón, D., Gutiérrez, A., Castilllo, M.J., et al. (2009). Aspectos fisiológicos de la escalada deportiva. *Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 9*(35), 264-298.

Frederic, N., Quaine, F., & Martin, L. (2001). Influence of step gradient supporting walls in rock climbing: biomechanical analysis. *Gait and Posture, 13*(2), 86-94.

Fryer, S. M., Giles, D., Garrido-Palomino, I., de la O Puerta, A., & España-Romero, V. (2018). Hemodynamic and cardiorespiratory predictors of sport rock climbing performance. *Journal of Strength Conditioning Research, 32*(12), 3543–3550.

Fuss, F.K., & Niegl, G. (2010). Biomechanics of the two-handed dyno technique for sport climbing. *Sports Engineering, 13*, 19–30.

Giles, L. V., Rhodes, E. C., & Taunton, J. E. (2006). The physiology of rock climbing. *Sports Medicine, 36*(6), 529-545.

Konstantin, F., & Niegl, G. (2012). The importance of friction between hand and hold in rock climbing. *Sport Technology*, *5*(34), 90-99.

Limonta, E., Cè, E., Gobbo, M., Veicsteinas, A., Orizio, C., & Esposito, F. (2016). Motor unit activation strategy during a sustained isometric contraction of finger flexor muscles in elite climbers. *Journal of Sports Sciences, 34*(2), 133–142.

Lopez-Rivera, E., & Gonzalez-Badillo, J. J. (2012). The effects of two maximum grip strength training methods using the same effort duration and different edge depth on grip endurance in elite climbers. *Sport Technology*, *5*(3-4), 100-110.

Mermier, C. M., Janot, J. M., Parker, D. L., & Swan, J. G. (2000). Physiological and anthropometric determinants of sport climbing performance. *British Journal of Sports Medicine, 34*, 359-366.

Michailov, M. L., Baláš, J., Tanev, S. K., Andonov, H. S., Kodejška, J., & Brown, L. (2018). Reliability and validity of finger strength and endurance measurements in rock climbing. *Research Quarterly for Exercise and Sport, 89*(2), 246–254.

Morenas, J., Luis, V., Leyton, M., Gomez-Valadés, J. M., & Gomez, J. (2013). Description of the finger mechanical load of climbers of different levels during different hand grips in sport climbing. *Journal of Sports Sciences*, *31*(15), 1713-1721.

Núñez, V. M., Ramírez, J. M., Lancho, C., Poblador, M. S., y Lancho, J. L. (2018). La resistencia de los músculos flexores de los dedos de la mano en escaladores. *Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 18*(69), 43-59.

Orth, D., Davids, K., & Seifert, L. (2016). Coordination in Climbing: Effect of skill, practice and constraints manipulation. *Sports Medicine, 46*(2), 255-268.

Russell, S., Zirker, C., & Blemker, S. (2012). Computer models offer new insights into the mechanics of rock climbing. *Sport Technology*, *5*(3-4), 120-131.

Salkind, N.J. (1999). *Exploring research*. Englewood Cliffs, NJ: Prentice Hall.

Seifert, L., Wattebled, L., Herault, R., Poizat, G., Adé, D., Gal-Petitfaux, N., et al. (2014). Neurobiological degeneracy and affordance perception support functional intra-individual variability of inter-limb coordination during ice climbing. *PLoS One*, *9*(2): e89865.

Seifert, L., Wattebled, L., L´Hermette, M., Bideault, G., Herault, R., & Davids, K. (2013). Skill transfer, affordances and dexterity in different climbing environments. *Human Movement Science, 32*, 1339-1352.

Sheel, A. W. (2004). Physiology of sport rock climbing. *British Journal of Sports Medicine*, *38*(3), 355–359.

Sibella, F., Frosio, I., Schena, F., & Borghese, N. A. A. (2007). 3D analysis of the body center of mass in rock climbing. *Human Movement Science, 26*(6), 841–852.

Saul, D., Steinmetz, G, Lehmann, W., & Schilling, A. F. (2019). Determinants for success in climbing: A systematic review. *Journal of Exercise Science & Fitness, 17*, 91–100.

Úbeda, A. B. (2004). Valoración de la fuerza de agarre en escaladores. *Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 4*(14), 122-143.

Vigouroux, L., & Quaine, F. (2006). Fingertip force and electromyography of finger flexor muscles during a prolonged intermittent exercise in elite climbers and sedentary individuals. *Journal of Sports Sciences, 24*(2), 181–186.

Vigouroux, L., Quaine, F., Labarre-Vila, A., & Moutet, F. (2006). Estimation of finger muscle tendon tensions and pulley forces during specific sport climbing grip techniques. *Journal of Biomechanics, 39*, 2583-2592.

Watts, P. B. (2004). Physiology of difficult rock climbing. *European Journal Applied Physiology, 91*, 361–372.

Watts, P. B., Martin, D. T., & Durtschi, S. (1993). Anthropometric profiles of elite male and female competitive sport rock climbers. *Journal of Sports Sciences, 11*(2), 113–117.

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