Journal of Physical Education and Sport ® (JPES), Vol. 22 (issue 12), Art 396, pp. 3128-3134, December 2022
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Movement analysis of the starting phase of 15-m speed climbing: a case study of thai national rock climber

TATPICHA PONGSIRI[1], VORRAMATE PRAJONGJAI[2], NONGNAPAS CHAROENPANICH[3*]
[1,3]Faculty of Sports Science, Chulalongkorn University, THAILAND
[2]Faculty of Science, Chandrakasem Rajabhat University, THAILAND

Published online: December 25, 2022
(Accepted for publication December 15, 2022)
DOI:10.7752/jpes.2022.12396

Abstract:
Speed climbing is the most dynamic discipline among all climbing sports that involves an optimization of the ascensional velocity. The result of competition depends on the time of climbing 15 m; therefore, all climbers try to improve their speed of climbing. The phases of climbing include the starting, second, third, and ending phases. The starting phase is the most importance phase, because the climbers should increase their speed from zero to the highest speed, which is seventy-five to one-hundred percent of the maximum climbing speed. There are two patterns for passing the starting phase, i.e., the classic start and the Tomoa skip. The classic start passes the starting phase by catching the 4th hand hold before catching the 5th hand hold, whereas the Tomoa skip does not. Thus, the Tomoa skip is an interesting starting pattern to improve maximum climbing speed, but there are few 3D analyses to show how the climber moves using that pattern. The purpose of this study was to perform a 3D analysis and compare the movement between the classic start and Tomoa skip during the starting phase of fifteen-meter speed climb. One Thai national rock climber was chosen to climb at an indoor speed climbing competition. Eight high-speed cameras were placed in front of and next to the rock wall. Fourteen retroreflective markers were placed on both sides of upper and lower extremities, spinous process of the 7th cervical vertebra, and center of harness. The climber was allowed to climb as fast as he could using 2 starting patterns, i.e., the classic start and Tomoa skip. The movement of the climber during the starting phase, especially from the 3rd to the 5th hand hold, was analyzed. The obtained results showed that the Tomoa skip starting pattern had shorter distance than the classic start; therefore, this pattern required less time but higher speed than the other pattern. In the Tomoa skip pattern, the climber moved by leaping from the 3rd to the 5th hand hold using the right leg to kick the hold vertically simultaneously with the right hand catching the 5th hand hold. On the other hand, in the classic start, the climber tilted the body to catch the 4th hand hold and then tilted back to the 5th hand hold. Therefore, using the Tomoa skip, the climber moves shorter distance at higher speed than in the classic start when moving in the vertically direction. Thus, the Tomoa skip start is the better pattern of starting than the classic start because it minimizes lateral displacement and leads to shorter distance and higher speed.
Key words*:* **Movement analysis / Starting phase / Classic start / Tomoa skip / Speed climbing**

Introduction

Rock climbing is one of the extreme sports that is popular because it is fun, challenging, and has high rate of repetition. The climbers need to train their body's endurance and strength, especially the upper extremities, because speed climbing requires the power to climb and transport the body vertically (Watts, 2004 and Quaine and Vigouroux, 2004). The sport of rock climbing can be divided into 2 types, i.e., indoor and outdoor. There are 3 types of competitions, i.e., bouldering, lead, and speed. The bouldering and lead competitions are complex climbing that depend on the route of climbing in competition. The level of difficulty makes the cheering team feel excited, but it is hard to understand all routes of climbing. On the other hand, speed climbers compete on the same route and judged on their time of climbing; therefore, speed climbing is more popular. Speed climbing is a dynamic discipline among all climbing sports; it involves an optimization of the ascensional velocity during the climb (Krawczyk et al.,2017).

Speed climbing starts after a starting beep; the climbers climb as fast as they can on an internationally standardized fifteen-meter wall consisting of 31 holds (20 hand holds and 11 foot holds), and the competition ends by touching a touch pad to stop the timer. Whoever used the least amount of time is the winner. There are four phases of the speed climbing route, i.e., the starting phase (from the start to the 9th hold), second phase (from the 9th hold to the 18th hold), third phase (from the 18th hold to the 28th hold), and end phase (from the end of the route to touching the touchpad) (Legreneur, Rogowski and Durif, 2019). To achieve the maximum speed, the climbers should increase their speed from the start to nearly the maximum speed as fast as they can; thus, the starting phase is the most importance phase in speed climbing. In the starting phase, the climbers increase speed to seventy-five to one-hundred percent of the maximum climbing speed. There are two patterns for passing the starting phase, i.e., the classic start and the Tomoa skip. In the classic start, the climbers pass the starting phase

Corresponding Author: NONGNAPAS CHAROENPANICH, E-mail: nongnapas.c@chula.ac.th

by catching the 4th hand hold. The climbers tilt the body diagonally from the 3rd to the 4th hand hold and tilt back from the 4th to the 5th hand hold using their leg for pushing in that direction (Reveret et al., 2018 and Shunko and Kravchuk, 2020). Whereas, during the Tomoa skip, the climbers skip the 4th hand hold by moving straight vertically through the starting section. Mr. Tomoa Narasaki is a Japanese climbing athlete who was the first to present the starting phase without catching the 4th hand hold; thus, this approach is called the "Tomoa skip" starting. The Tomoa skip pattern can significantly decrease the climbing time because the movement is performed immediately from the 3rd to the 5th hand hold. The starting position is exactly vertical, as is the position of the jogging leg. The direction of movement is set mainly by the hands (Shunko and Kravchuk, 2020).

Because the climbers using the Tomoa skip move shorter distance at higher speed, the Tomoa skip starting can allow to win the game, especially in speed competition. To improve the speed of climbing, 3D kinematic analysis can show how to start using the Tomoa skip. The 3D analysis is based on recording video from multiple cameras. There are many 3D studies in sports, e.g., a study on the relationship between biomechanical factors (i.e., 3D kinematic analysis and ground reaction force) and the performance of golf swing (Chu et al, 2010), a kinematic analysis of short and long services for improving service performance in badminton players (Shen, 2014), and a kinetic analysis of backhand short serve in badminton players (Prajongjai et al, 2021). The analyzed movement patterns are used as ideal patterns for learning. Thus, the analysis of Tomoa skip pattern can be used to improve the starting phase and increase the speed of climbing in speed competition.

The 3D analysis method was used to analyze the movement using high-speed cameras to create a 3-dimensional picture. At least 2 cameras should detect the target marker. This technique is very useful for improving the performance; however, it is very difficult and expensive to analyze climbing movement; thus, there are other variables that explain the performance of climbing such as cardiovascular performance and physiological characteristics (Shunko, 2020). The 3D analysis is still important. A study performed in 2020 tried to use 3D analysis with high-speed cameras to analyze the movement pattern; however, the study was performed in a laboratory (Iguma, 2020). There are very few analyses in real rock climbing.

The purpose of this study was to analyze and compare the movement during the starting phase of fifteen-meter speed climb between the classic start and the Tomoa skip. Ethical approval was obtained by the Institute Ethics Review Committee for Research Involving Human Project, Thailand

Materials and Methods

One male climber (Thai national rock climber, the winner of speed climbing ASEAN university games 2022, mass = 63 kg, height = 1.84 m) performed 6 maximal speed ascents on the official route (Fig. 1) using the Tomoa skip (3 times) and the classic start (3 times), with 5-min rest between each climb and 10-min rest between climbing styles. The mean ascent time for the Tomoa skip was 6.73 s, and 11.53 s for the classic start. We selected the best trial (ascent time of the Tomoa skip = 6.68 s and of the classic start = 10.81 s) for the analysis.

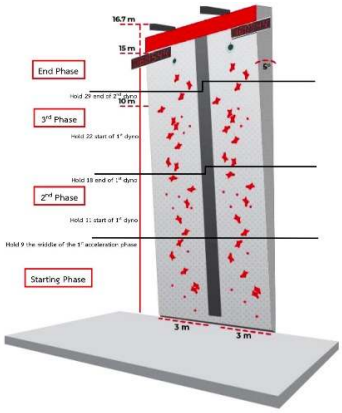

Fig. 1 The official route

3D kinematic data were captured with fourteen markers that were placed on both sides of the acromion process, lateral epicondyle, ulnar styloid process, posterior superior iliac spine (PSIS), lateral femoral condyle, lateral malleolus and spinous process of the 7th cervical vertebra (C7), and the center of mass of the subject was approximated by a marker attached to his harness, close to the middle of the pelvic ilium bones to analyze the climbing movement (Cordier et al., 1993 and Reveret et al., 2020) (Fig. 2). The angle displacement of joints was calculated from each of 3 markers, i.e., the shoulder angle (C7–acromion process–lateral epicondyles of the humerus), elbow angle (acromion process–lateral epicondyles of the humerus–ulnar styloid process), hip angle (C7–PSIS–lateral femoral condyle), and knee angle (PSIS–lateral femoral condyle–lateral malleolus).

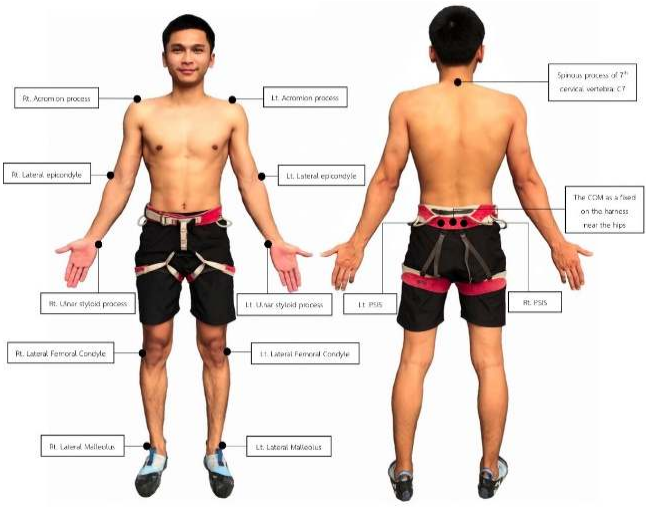

Fig. 2 Fourteen retro-reflective marker positions

Qualisys Track Manager (QTM) was operated at 300 Hz using eight cameras that were fixed on a 3D axis stabilization platform to show phases of climbing movement (Fig. 3). There are 8 high-speed infrared-based cameras (Oqus7+, Sweden) and one VDO-based camera set in front of and next to the rock route, respectively. We considered starting phases for analyzing the movement, from the start to the middle of the first acceleration phase (9th hold). All cameras were set along the route and calibrated for accuracy, specifically around the 3rd to 5th hand hold. The shortest times for the classic start and the Tomoa skip from all 3 trials for each pattern were analyzed.

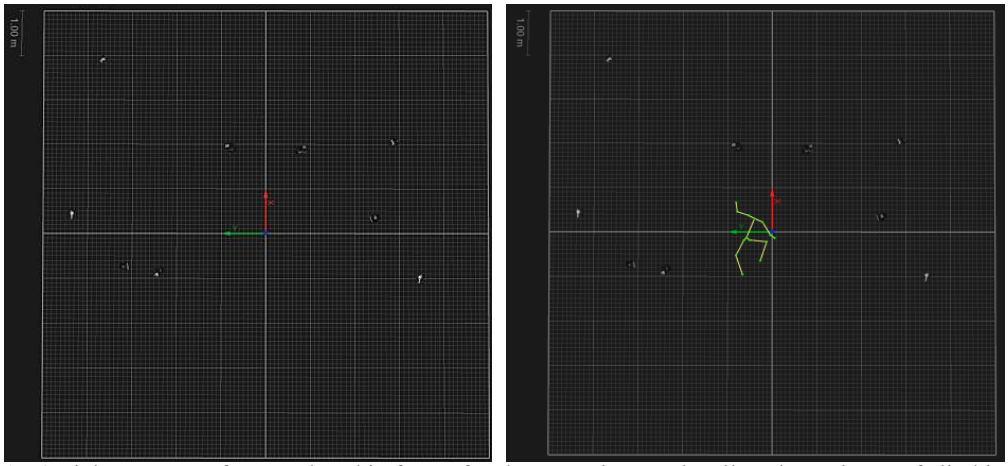

Fig. 3 Eight cameras of QTM placed in front of and next to the speed wall to show phases of climbing movement

Results and discussion

The kinematic data for the classic start and the Tomoa skip are shown in Table 1.

Table 1. The climbing speed, climbing time and climbing distance for the classic start and the Tomoa skip

Starting Pattern / Variable	Classic Start	Tomoa Skip
Climbing Speed (m/s)		
Hold 3rd to Hold 4th	1.05	-
Hold 4th to Hold 5th	0.67	-
Hold 3rd to Hold 5th	1.51	2.28
Climbing Time (s)		
Hold 3rd to Hold 4th	0.66	-
Hold 4th to Hold 5th	1.52	-
Hold 3rd to Hold 5th	2.18	0.76
Distance (meter)		
Hold 3rd to Hold 4th	0.69	-
Hold 4th to Hold 5th	1.02	-
Hold 3rd to Hold 5th	3.29	1.73

The results in Table 1 show that the climber using the classic start moved from the 3rd to 4th hand hold and then from the 4th to 5th hand hold with a climbing speed of 1.05 and 0.67 m/s, climbing time of 0.66 and 1.52 s, and distance 0.69 and 1.02 m, respectively. After calculating the values from the 3rd to the 5th hand hold, the climber using the classic start showed the climbing speed of 1.52 m/s, climbing time of 2.18 s, and distance of movement of 3.29 m. On the other hand, the climber using the Tomoa skip showed the climbing speed of 2.28 m/s, climbing time of 0.76 s, and distance of movement of 1.73 m.

The obtained results clearly showed that the Tomoa skip had a different movement patterns compared to the classic start because of the different route. In the classic start, the climber tilted the body diagonally to the 4th hand hold before tilting back to the 5th hand hold. Therefore, in the classic start, the climber needs to move for a longer distance (approximately 1.56 m), at lower speed (0.77 m/s), and waste more time (1.42 sec) for the same vertical distance compared to the Tomoa skip.

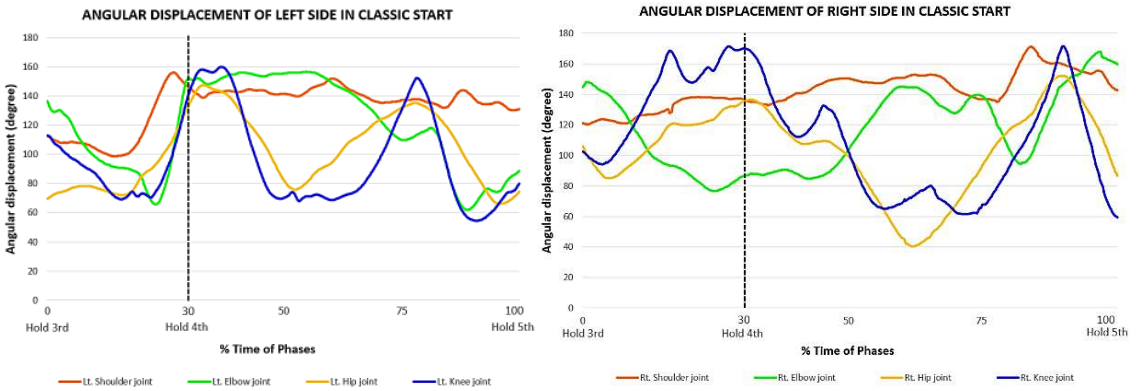

Fig.4 Angular displacement of the classic start

Figure 4 shows the angular displacement of both sides of the shoulder, elbow, hip, and knee joint for the classic start; it is shown that there are 2 movement steps, i.e., movement from the 3rd to the 4th hand hold and from the 4th to the 5th hand hold. The movement from the 3rd to the 4th and from the 4th to the 5th hand holds depend on the left ulnar styloid process, which moved from the 3rd hand hold to the 4th hand hold and ended the phase of movement when right ulnar styloid process moved to the 5th hand hold.

During the movement from the 3rd to the 4th hand hold, the left side showed a decrease in the angle of the initial movement and then an increase in the angle at the end phase. This means that during the movement from the 3rd to the 4th hand hold, the climber moved the hand to the body by extending the shoulder and flexing the elbow joint, while simultaneously moving with more flexion of the hip and knee joint to the next foot hold. During the next phase, the climber stretched the left arm to the 4th hand hold while simultaneously stretching the left leg to move the body to 4th hand hold. At the same time, for the right side of the body, the climber flexed the elbow with a slightly extended shoulder to move the hand over the head to prepare to catch the 5th hand hold while simultaneously performing the right hip and knee extension movement.

To move from the 4th to 5th hand hold, the left side performed an extension movement of the shoulder and changed the elbow angle compared to the left hip and knee, which performed an extension movement to kick the foot hold to send the body to the 5th hand hold and return to the extension movement. Simultaneously with the right side, shoulder angle showed an extension movement with elbow flexion. The elbow angle showed an extension movement at the initial phase, and then the elbow extended to catch the 5th hand hold.

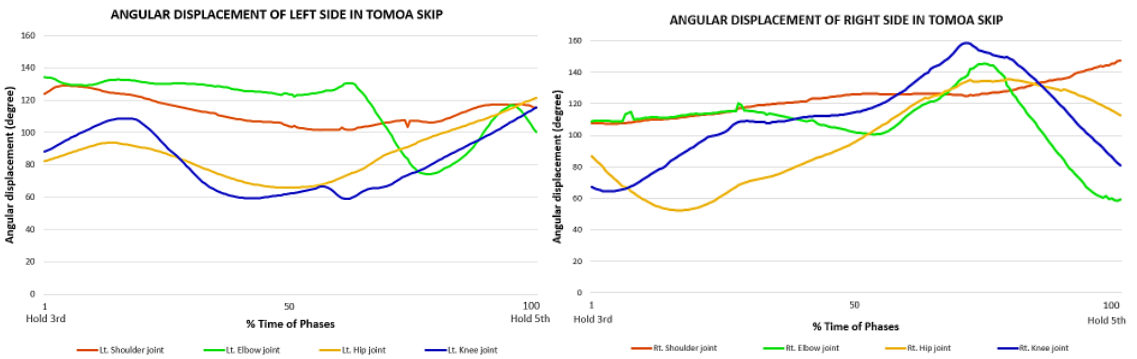

Fig. 5 Angular displacement during the Tomoa skip

Figure 5 shows that the Tomoa skip had only one phase of movement, i.e., movement from the 3rd to the 5th hand hold. The angular displacement of the shoulder, elbow, hip, and knee showed a smooth movement pattern. The left shoulder showed a slight flexion movement, whereas the elbow angle showed an extension and then flexion in the late phase. Simultaneously, the hip and knee angle showed a flexion movement followed by extension in the late phase. The right shoulder angle showed a slight flexion movement, whereas the elbow angle showed flexion in the middle phase followed by quick extension and return to flexion in the late phase. Simultaneously, the hip and knee angle showed an extension movement followed by flexion in the late phase.

The obtained results showed that using the Tomoa skip, the climber moved from the 3rd to the 5th hand hold by stretching both sides of the upper and lower limbs, which straightens the body and moves it vertically by extending the hip and knee, while the elbow and shoulder joints perform flexion movements in addition to the jogging leg followed by extension to stretch the body for skipping the 4th hand hold and going straight vertically through the initial phase (Fig. 5). Development in the speed climbing is represented by the Tomoa skip starting pattern, which is characterized by the starting position being exactly vertical to minimize lateral displacement to increase fluency and maintain high velocity levels along the acceleration phases. Therefore, the climber using the Tomoa skip moves for a shorter distance during the starting phase with faster climbing speeds than during the classic start.

Conclusions

The classic start is a traditional pattern in speed climbing, whereas the Tomoa skip is a new pattern that improves climbing speed, which is useful for speed climbing competition. This study shows that the Tomoa skip requires less time for climbing, i.e., the movement from the 3rd to the 5th hand hold required 1.42 s. Therefore, the Tomoa skip start is a more effective pattern than the classic start because the Tomoa skip minimizes lateral displacement, which results in shorter distance and higher movement speed. The obtained results showed that the climber using the Tomoa skip moves vertically by ejecting the body from the 3rd to the 5th hand hold, by extending the left hip and knee joint, which simultaneously flexing the right hip and knee joint and sending both arms to reach the 5th hand hold. Therefore, the Tomoa skip can increase the chances of winning in a speed climbing competition. This case presentation is an in-depth analysis that shows how the climbers move their limbs to send their body vertically. There are still additional questions that need to be answered. Specifically, is there coordination between upper and lower limbs to achieve effective climbing with shorter movement time? Are there any factors that improve the performance of the Tomoa skip?

Acknowledgments

We gratefully acknowledge the participant in the study. We also thank the Faculty of Sports Science, Chulalongkorn University. Finally, the authors would like to thank Falcon Scientific Editing (https://falconediting.com) for proofreading the English language in this paper.

References:

Bertuzzi, R., Franchini, E., Tricoli, V., Lima-Silva, A. E., Pires, F. O., Okuno, N. M., & Kiss, M. A. (2012). Fit-climbing test: a field test for indoor rock climbing. *The Journal of Strength & Conditioning Research*, *26*(6), 1558-1563.

Coppola, S., Albano, D., Sivoccia, I., & Vastola, R. (2020). Biomechanical analysis of a rhythmic gymnastics jump performed using two run-up techniques. *Journal of Physical Education and Sport*, *20*(1), 37-42.

Cordier, P., France, M. M., Bolon, P., & Pailhous, J. (1993). Entropy, degrees of freedom, and free climbing: A thermodynamic study of a complex behavior based on trajectory analysis. *International Journal of Sport Psychology*.

Cossor, J., & Mason, B. (2001). Swim start performances at the Sydney 2000 Olympic Games. In *ISBS-Conference Proceedings Archive*.

Deyhle, M. R., Hsu, H. S., Fairfield, T. J., Cadez-Schmidt, T. L., Gurney, B. A., & Mermier, C. M. (2015). Relative importance of four muscle groups for indoor rock climbing performance. *The Journal of Strength & Conditioning Research*, *29*(7), 2006-2014..

Espana-Romero, V., Jensen, R. L., Sanchez, X., Ostrowski, M. L., Szekely, J. E., & Watts, P. B. (2012). Physiological responses in rock climbing with repeated ascents over a 10-week period. *European Journal of Applied Physiology*, *112*(3), 821-828.

Fernandes, T. L. B., Assumpcao, C. D. O., de Oliveira, S. F. M., Fermino, R. C., & Vilas-Boas, J. P. (2021). Single marker method to estimate center-of-mass velocity during vertical jumps. *Journal of Physical Education and Sport*, *21*(5), 2458-2465.

Fischer, F., Bachinski, M., Klar, M., Fleig, A., & Müller, J. (2021). Reinforcement learning control of a biomechanical model of the upper extremity. *Scientific Reports, 11*(1), 1-15.

Giles, D., Romero, V. E., Garrido, I., de la O Puerta, A., Stone, K., & Fryer, S. (2017). Differences in oxygenation kinetics between the dominant and nondominant flexor digitorum profundus in rock climbers. *International Journal of Sports Physiology and Performance, 12*(1), 137-139.

Grant, S., Hynes, V., Whittaker, A., & Aitchison, T. (1996). Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. *Journal of Sports Sciences*, *14*(4), 301-309.

Guo, F., Wang, Q., Liu, Y., & Hanson, N. J. (2019). Changes in blood lactate and muscle activation in elite rock climbers during a 15-m speed climb. *European Journal of Applied Physiology*, *119*(3), 791-800.

Iguma, H., Kawamura, A., & Kurazume, R. (2020). A New 3D Motion and Force Measurement System for Sport Climbing. In *2020 IEEE/SICE International Symposium on System Integration (SII)* (pp. 1002-1007). IEEE.

Izzo, R., Gagliardi, M., Raiola, G., Cejudo, A., & Varde'i, C. H. (2020). Video analysis evaluation of goal actions using a new tactical analytic approach. *Journal of Physical Education and Sport*, *20*, 2151-2158.

Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2021). *Physiology of sport and exercise*. Human kinetics.

Kompán, J., Svidroňová, M. M., & Maslen, M. (2021). Climbing literacy project for children and youth: a utility analysis. *Journal of Physical Education and Sport*, *21*, 2074-2080.

Kozina, Z., Uvarova, N., Cieslicka, M., Bejtka, M., & Jagiełło, M. (2020). Experimental substantiation of the program of the annual cycle of preparation of climbers 16-17 years to the competitive discipline" Climbing Combined". *Journal of Physical Education and Sport*, *20*, 1250-1257.

Krawczyk, M., Ozimek, M., Rokowski, R., Pociecha, M., & Draga, P. (2017). Level of selected speed ability indexes of lower limb in relation on climbing time in speed climbing. In *The Second International Scientific Conference Motor Abilities in Sports-Theoretical Assumptions and Practical Implications*.

Krawczyk, M., & Ozimek, M. (2014). Somatic traits and motor skill abilities in top-class professional speed climbers compared to recreational climbers. *Antropomotoryka. Journal of Kinesiology and Exercise Sciences*, *66*, 25-32.

Legreneur, P., Rogowski, I., & Durif, T. (2019). Kinematic analysis of the speed climbing event at the 2018 Youth Olympic Games. *Computer Methods in Biomechanics and Biomedical Engineering*, *22*(sup1), S264-S266.

Levernier, G., Samozino, P., & Laffaye, G. (2020). Force–velocity–power profile in high-elite boulder, lead, and speed climber competitors. *International Journal of Sports Physiology and Performance*, *15*(7), 1012-1018.

Limonta, E., Cè, E., Veicsteinas, A., & Esposito, F. (2008). Force control during fatiguing contractions in elite rock climbers. *Sport Sciences for Health*, *4*(3), 37-42.

Magiera, A., Roczniok, R., Maszczyk, A., Czuba, M., Kantyka, J., & Kurek, P. (2013). The structure of performance of a sport rock climber. *Journal of Human Kinetics*, *36*(1), 107-117.

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*(5), 359-365.

Michailov, M. L. (2014). Workload characteristic, performance limiting factors and methods for strength and endurance training in rock climbing. *Medicina Sportiva*, *18*(3), 97-106.

Muehlbauer, T., Stuerchler, M., & Granacher, U. (2012). Effects of climbing on core strength and mobility in adults. *International Journal of Sports Medicine*, *33*(06), 445-451.

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

Ozimek, M., Krawczyk, M., Rokowski, R., Draga, P., Ambroży, T., Mucha, D., & Görner, K. (2018). Evaluation of the level of anaerobic power and its effect on speed climbing performance in elite climbers.

Philippe, M., Wegst, D., Müller, T., Raschner, C., & Burtscher, M. (2012). Climbing-specific finger flexor performance and forearm muscle oxygenation in elite male and female sport climbers. *European Journal of Applied Physiology*, *112*(8), 2839-2847.

Quaine, F., & Martin, L. (1999). A biomechanical study of equilibrium in sport rock climbing. *Gait & Posture*, *10*(3), 233-239.

Quaine, F., & Vigouroux, L. (2004). Maximal resultant four fingertip force and fatigue of the extrinsic muscles of the hand in different sport climbing finger grips. *International Journal of Sports Medicine*, *25*(08), 634-637.

Quaine, F., Vigouroux, L., & Martin, L. (2003). Finger flexors fatigue in trained rock climbers and untrained sedentary subjects. *International journal of sports medicine*, *24*(06), 424-427.

Reveret, L., Chapelle, S., Quaine, F., & Legreneur, P. (2018). 3D motion analysis of speed climbing performance. In *4th International Rock Climbing Research Congress*.

Reveret, L., Chapelle, S., Quaine, F., & Legreneur, P. (2020). 3D visualization of body motion in speed climbing. *Frontiers in Psychology*, *11*.

Saul, D., Steinmetz, G., Lehmann, W., & Schilling, A. F. (2019). Determinants for success in climbing: A systematic review. *Journal of Exercise Science & Fitness*, *17*(3), 91-100.

Shunko, A., & Kravchuk, T. (2020). Competitive modelling in speed climbing. In *BIO Web of Conferences* (Vol. 26, p. 00051). EDP Sciences.

Vorramate Prajongjai, Saowanee Woravutrangkul, Tatpicha Pongsiri, Nongnapas Charoenpanich (2021). The Analysis of Force Transfer between Feet during Backhand Short Serve in Elite Badminton Players. *International Journal of Human Movement and Sports Sciences, 9*(5), 1011 - 1018. DOI: 10.13189/saj.2021.090523.

Wall, C. B., Starek, J. E., Fleck, S. J., & Byrnes, W. C. (2004). Prediction of indoor climbing performance in women rock climbers. *The Journal of Strength & Conditioning Research*, *18*(1), 77-83.

Watts, P. B. (2004). Physiology of difficult rock climbing. *European Journal of Applied Physiology*, *91*(4), 361-372.

Watts, P. B., Joubert, L., Lish, A. K., Mast, J. D., & Wilkins, B. (2003). Anthropometry of young competitive sport rock climbers. *British Journal of Sports Medicine*, *37*(5), 420-424.

Watts, P., Newbury, V., & Sulentic, J. (2010). Acute changes in handgrip strength, endurance, and blood lactate with sustained sport rock climbing. *The Journal of Sports Medicine and Physical Fitness*, *36*(4), 255-260.

White, D. J., & Olsen, P. D. (2010). A time motion analysis of bouldering style competitive rock climbing. *The Journal of Strength & Conditioning Research*, *24*(5), 1356-1360.