INTER-LIMB COORDINATION VARIABILITY IN ICE CLIMBERS OF DIFFERENT SKILL LEVEL

Ludovic Seifert[1], Leo Wattebled[1], Maxime L'Hermette[1], Romain Herault[2]
University of Rouen[1], Faculty of Sports Sciences, France
National Institute of Applied Sciences (INSA)[2], Rouen, France

ABSTRACT

Research background and hypothesis. Ice climbers determine their own ascent paths by creating holes with their crampons and ice tools. The coupling of upper and lower limbs thus emerges from the icefall environment without prescriptions for one mode of coordination.

Research aim. The aim of this study was to analyse the upper / lower limb coordination of ice climbers of different skill level and to explore how the environmental constraint (ice fall shape) is used by the climbers to adapt their motor behaviour.

Research methods. Six elite ice climbers and five beginners climbed a 30m icefall, respectively in grade 5 / 5+ and grade 4. Frontal camera videotaped the first 15m of the ascent, then the left and right ice tools and the left and right crampons were digitalised in order to analyse the upper limbs coupling, the lower limbs coupling and the upper / lower limb coordination.

Research results. The results indicated that in-phase mode of upper / lower limb coordination was the main attractor for both groups. However, elite climbers showed greater variability in their behaviour, exploring larger range of upper and lower angles (particularly vertical and crossed positions) and types of movement (ice tool swinging and ice hole hooking).

Discussion and conclusions. It was concluded that holes in ice fall, and more globally ice fall shape, were affordances that induced variable upper / lower limb coordination in elite climbers, whereas beginners used a basic and stable motor organization in order to maintain body equilibrium.

Keywords: upper / lower limb coordination, environmental constrains, types of movement.

INTRODUCTION

Rock climbing is a complex skill imposing postural constraints to grasp holds. C. Bourdin et al. (1999) postulated that high postural constraints lead to a re-organization of the grasping movement by decreasing the duration of the movement up to contact, in order to maintain equilibrium. In other words, the climbers usually try to minimize the duration of the tripodal position by fast hold grasping, whatever the complexity of the hold to grasp. In ice climbing (climbing with ice tools and crampons on frozen water fall), the climbers could either swing their ice tool to create their own hole or use an existing hole (due to previous climbs or natural hole). The ice tool swinging involved a tripodal position that could take more or less time as regards the number of ice tool swinging done by the climber. Thus, ice climbing could correspond to an alternation between ice tool swinging, crampon kicking and arm pulling associated to leg pushing. As rock and ice climbing correspond to complex skill involving both upper and lower limbs, the climbers have to organize their coupling in order to maintain equilibrium and to travel a great distance between each ice tool swinging and crampon kicking.

Studies of inter-limb coordination during oscillating on a ski simulator (Vereijken et al., 1992), volley ball serve (Temprado et al., 1997), or swimming (Seifert et al., 2010) showed that beginners freeze the degrees of freedom while expert release the degrees of freedom not useful to the task. Freezing the degrees of freedom is mostly related to a basic coordination mode like in-phase (reflecting iso-direction or iso-contraction of two limbs; Swinnen et al., 1997), while releasing the degrees of freedom corresponds to out-of-phase, notably the anti-phase coordination mode (Vereijken et al., 1992; Temprado et al., 1997; Seifert et al., 2010).

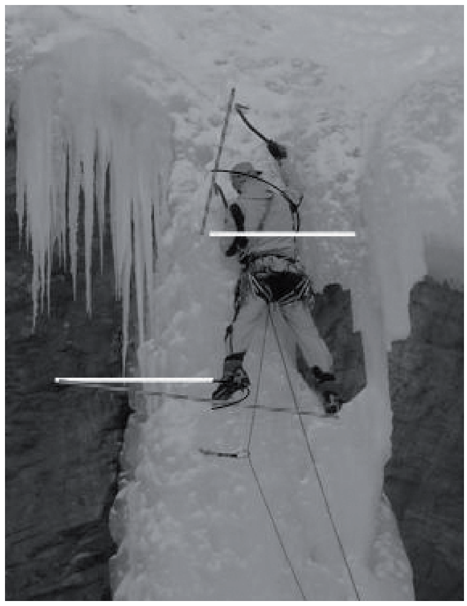
Ice climbers determine their own ascent paths by creating holes with their crampons and ice tools. The coupling of upper and lower limbs thus emerges from the icefall environment without prescriptions for in- or out-of-phase. The aim of this study was to analyse the upper / lower limb coordination of ice climbers of different skill level in order to explore how the existing holes in the icefall act as affordance for the climbers. It has been hypothesized that beginners mostly show an in-phase mode, being static for a long time or swinging too much with their ice tools. Conversely, the expert climbers would have their two ice tools asymmetric to travel great distance at each arm pulling, favouring out-of-phase coupling of upper / lower limbs.

RESEARCH METHODS

Participants and protocol. Six elite ice climbers (UIAGM mountain guides and instructors at the National School of Skiing and Alpinism – ENSA, climbing regularly at grade 6 climbed a 30m icefall at grade 5/5+ on the French rating scale (which goes from 1 to 7) (Batoux, Seifert, 2007). Six beginners (students at the Faculty of Sport Sciences with 20 hours of practice in wall climbing and inexperienced at ice climbing) climbed a 30m icefall at grade 4. All climbers were equipped with the same crampons and ice tools and were instructed to climb at their normal pace. The protocol was fully explained to the participants and they provided written consent to participate in the study, which was approved by the university ethics committee.

Data collection and analysis. A frontal camera (50 Hz) videotaped 15 m of the ascent (between 5 m and 20 m); this camera was placed at 15 m of the ice fall. A calibration frame delimited the recorded space of climbing and was composed of one vertical rope with marks every 2 m and two horizontal ropes (at 5 m and at 20 m) with marks every 1m (total of 20 marks for calibration). Four key points (the head of the left

Figure 1. **Angle between horizontal position, the left and the right limbs**



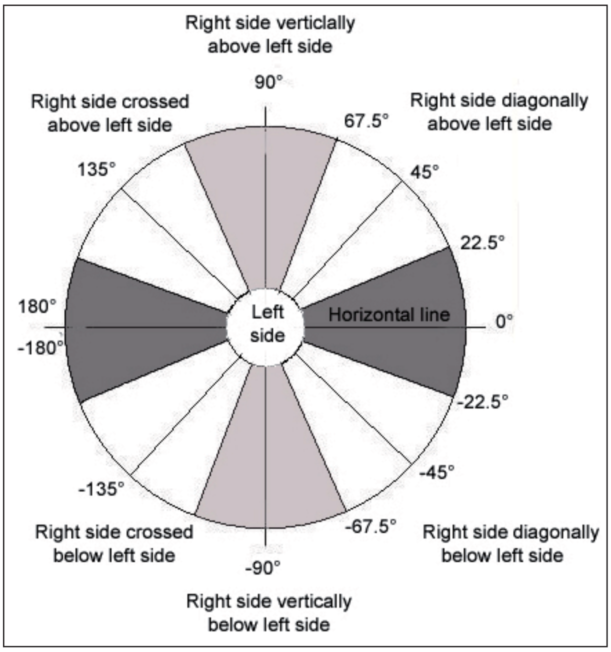


Figure 2. **Angle between horizontal position, the left limb and the right limb**

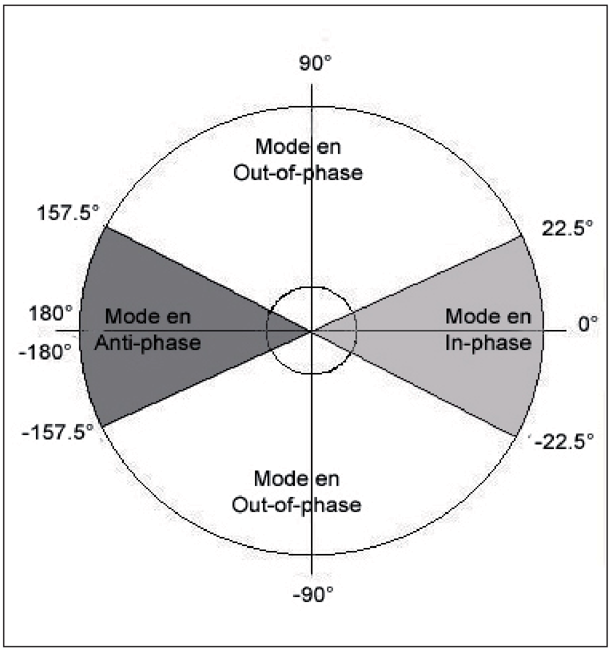


Figure 3. **Upper / lower limb coordination mode**

and the right ice tools and the extremity of left and right crampons) were digitalised using *Simi Reality Motion Systems GmbH ®,* 2004. Upper limb coupling was assessed by the angle between the horizontal line and the left and right ice tools, while lower limb coupling corresponded to the angle between the horizontal line and the left and right crampons (Fig. 1).

Thus, the angle between the horizontal line and the left and right limbs was positive when the right limb was above the left limb and negative when the right limb was below the left limb (Fig. 2).

The phase angles of the upper and lower limbs were obtained by Hilbert transform (Matlab 7.7 ® 1984–2008, The MathWorks, Inc.), usually calculated for non-periodic signals (van Emmerik et al., 2004; Balasubramaniam, Turvey, 2004; Palut, Zanone, 2005). Phase = arctan s (t) / iH (t), with s (t) as the real part and iH (t) the imaginary part of the signal. In our case, continuous relative phase (CRP) for upper / lower limb coordination corresponded to: $CRP = \arctan [H_{upper}(t) \cdot s_{lower}(t) - s_{upper}(t) \cdot H_{lower}(t)] / [s_{upper}(t) \cdot s_{lower}(t) - H_{upper}(t) \cdot H_{lower}(t)]$. In-phase mode was assumed to occur for $-22.5° < CRP < 22.5°$ (Fig. 3). Anti-phase mode was taken to be between $-80° < CRP < -157.5°$ and $157.5° < CRP < 180°$. Beyond this step, a coordination mode of intermediate phase was also taken into account.

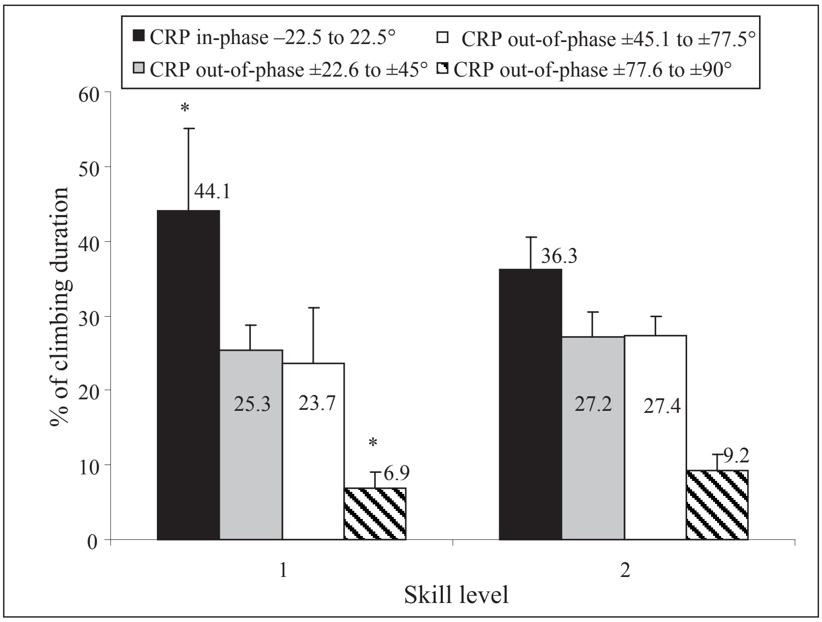
Statistics. The normality of the distribution (Ryan Joiner test) and the variance homogeneity (Bartlett test) were checked before using parametric statistics. Two ways ANOVA (fixed factor: skill level; random factor: subject) compared the upper limb angle, the lower limb angle and the upper / lower limb coordination between the two groups. All tests were conducted with Minitab 15.1.0.0 ® software (Minitab Inc., Paris, France, 2006) with a conventional significance level of $p < 0.05$.

RESEARCH RESULTS

Both groups showed an upper/lower limb coordination which is in average in in-phase mode (mean CRP = –2°). However, the elite climbers further varied their coordination during an ascent (standard deviation of CRP = 45.1°) compared to the beginners (standard deviation of CRP = 40.9°) ($p < 0.05$). The beginners spent more time with upper / lower limb coordination in in-phase mode, and less time in out-of-phase mode (for the class –77.6 to –90° and 77.6 to 90°) (Fig. 4).

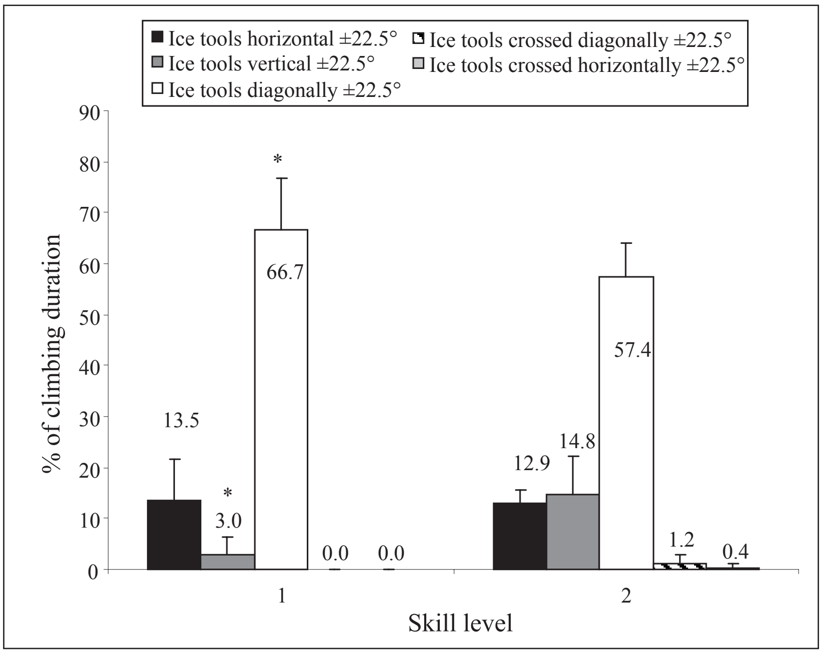
On average, during the whole period of climbing, both groups of climbers had their two ice tools horizontally (15.4° for beginners and 12.4° for elite climbers) and their crampons in horizontal position (24.1° for beginners and 19.8° for elite climbers). However, elite climbers further varied their upper limb angular position (standard deviation of ice tools angle = 50.2° *vs.* 31.1° for beginners) and their crampons angular position

Figure 4. **Continuous Relative Phase (CRP) spent in in-phase and out-of-phase mode**



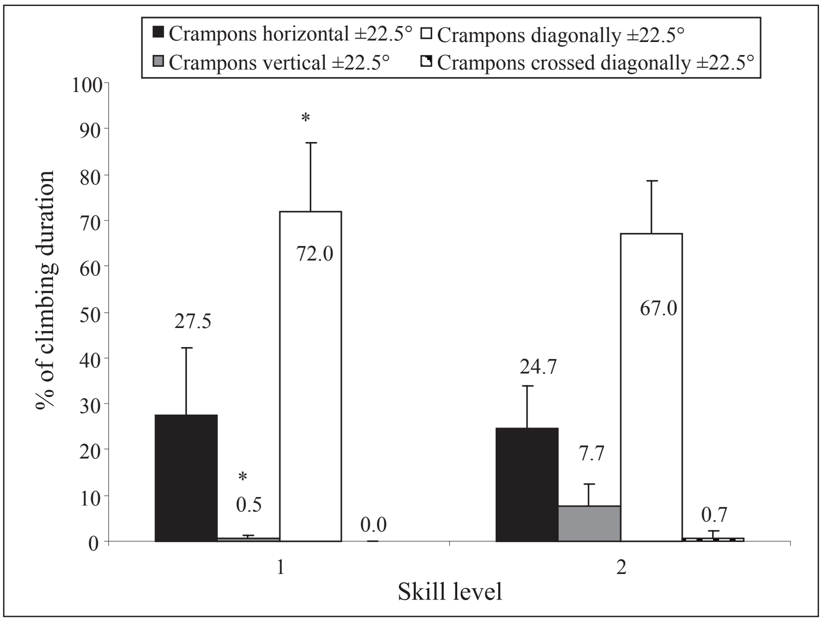
Note. Group 1 – beginners; group 2 – elite climbers; * – significant differences compared to group 2 at p < 0.05.

Figure 5. **Time spent with the ice tools in different angular positions**



Note. Group 1 – beginners; group 2 – elite climbers; * – significant differences compared to group 2 at p < 0.05.

Figure 6. **Time spent with the crampons in different angular positions**



Note. Group 1 – beginners; group 2 – elite climbers; * – significant differences compared to group 2 at p < 0.05.

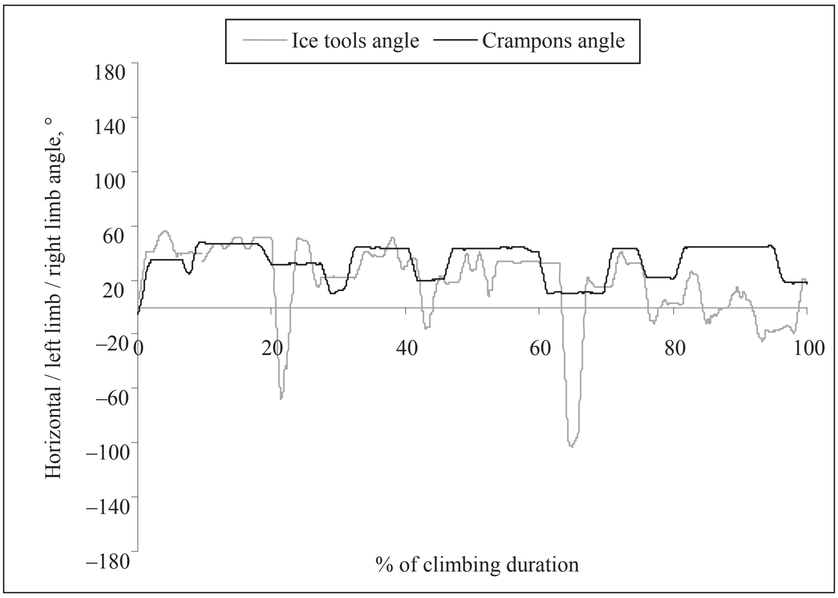


Figure 7. **Example of angle-time curve for ice tools and crampons angle of a beginner**

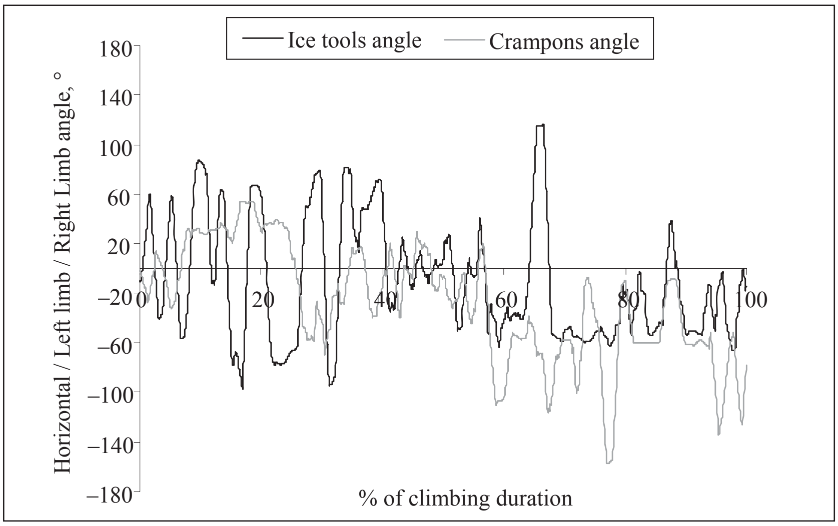


Figure 8. **Example of angle-time curve for ice tools and crampons angle of an elite climber**

(standard deviation of crampons angle = 38.7° *vs.* 25.0° for beginners) ($p < 0.05$). Beginners spent more time with their two ice tools and their two crampons diagonally and less time with their ice tools and their crampons in a vertical position than elite climbers ($p < 0.05$) (Figs. 5 and 6). Moreover, unlike the elite climbers, beginners never crossed their ice tools and their crampons (Figs. 5 and 6), which explained their lower variety of angular position and their upper/lower limb coordination mainly in in-phase mode.

DISCUSSION

Beginners mostly used one coordination mode (in-phase) and low variety in their upper / lower limb coordination. These results are in accordance with previous studies (Vereijken et al., 1992; Temprado et al., 1997; Seifert et al., 2010) highlighting that the beginners frozen their degrees of freedom. Freezing the degrees of freedom comes from the static "X" body position with the arms and legs extended (i. e. in-phase mode of coordination). In fact, their behaviour looked like climbing up a ladder, with an alternation of in-phase mode (i. e. body in "X" position) and of out-of-phase mode, the latter corresponding to (i) one arm swinging an ice tool while the two legs were extended or (ii) kicking in the crampons or pushing up with one foot while the arms pulled with the two ice tools at the same level. The dominance of the in-phase mode was due to the long time the beginners spent in a static position to find their way or to swing their ice tool and to kick their crampons in order to create deep holes. This behaviour reminds those observed in studies about rock climbing showing that if the climbers use a smaller number of holds to move along the artificial climbing wall, they have to be quick enough to maintain equilibrium;

and vice versa, if the number of holds is equal or greater than three, it means that they climb slowly because their equilibrium is always under control (Boschker et al., 2002; Sibella et al., 2007).

Figure 7 shows good example of in-phase mode of upper/lower limb coordination, corresponding to a beginner who often kept his ice tools and crampons angle in the same position (showing plateau in the angle-time curve).

Conversely, the elite ice climbers used a variety of motor solutions, notably for one ice tool swinging in a vertical position in comparison to the second ice tool, they move up their crampons two or three times (Fig. 8). They avoided the static "X" body position and too much ice tool swinging and crampon kicking, which may cause fatigue.

CONCLUSIONS AND PERSPECTIVES

The elite climbers hooked their ice tools into existing holes and put their crampons in the holes made by the ice tools, showing that the holes corresponded to affordances determining the behaviour of the elite climbers. Indeed, trying to interact as well as they can with the environment (i.e. the ice fall shape), the elite climbers sometimes crossed the right and left limbs to use existing holes in the ice fall. M. S. J. Boschker et al. (2002) have previously showed that expert rock climbers recalled more information and they focused on the functional aspects of a climbing wall, whereas they neglected its structural features. Conversely, the beginners did not recall such information and they reported almost exclusively the structural features of the holds (Boschker et al., 2002). It confirmed that hold in rock climbing and hole in ice climbing looked like affordances for expert whereas it induced less motor adaptation in beginners.

REFERENCES

Balasubramaniam, R., Turvey, M. T. (2004). Coordination modes in the multisegmental dynamics of hula hoping. *Biological Cybernetics*, 90, 176–190.

Batoux, P., Seifert, L. (Eds.). (2007). *Ice Climbing and Dry Tooling: From Leman to Mont Blanc.* Chamonix, France: JMEditions.

Boschker, M. S. J., Bakker, F. C., Michaels, C. F. (2002). Memory for the functional characteristics of climbing walls: Perceiving affordances. *Journal of Motor Behavior*, 34, 25–36.

Bourdin, C., Teasdale, N., Nougier, V., Bard, C., Fleury, M. (1999). Postural constraints modify the organization of grasping movements. *Human Movement Science*, 18, 87–102.

van Emmerik, R. E. A, Rosenstein, M. T., McDermott, W. J., Hamill, J. (2004). A nonlinear dynamics approach to human movement. *Journal of Applied Biomechanics*, 20, 396–420.

Palut, Y., Zanone, P. G. (2005). A dynamical analysis of tennis: Concepts and data. *Journal of Sports Sciences*, 23, 1021–1032.

Seifert, L., Leblanc, H., Chollet, D., Delignières, D. (2010). Inter-limb coordination in swimming: Effect of speed and skill level. *Human Movement Science*, 29, 103–113.

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

Swinnen, S. P., Jardin, K., Meulenbroek, R., Douskaia, N., Hofkens-Van Den Brandt, R. (1997). Egocentric and allocentric constraints in the expression of patterns of inter-limb coordination. *Journal of Cognitive Neuroscience*, 9, 348–377.

Temprado, J., Della Grasta, M., Farrell, M., Laurent, M. (1997). A novice-expert comparison of (intra-limb) coordination subserving the volleyball serve. *Human Movement Science*, 16, 653–676.

Vereijken B., van Emmerik, R. E. A., Whiting H. T. A., Newell, K. M. (1992). Freezing degrees of freedom in skill acquisition. *Journal of Motor Behaviour*, 24, 133–142.

SKIRTINGO MEISTRIŠKUMO LEDO ALPINISTŲ RANKŲ IR KOJŲ TARPUSAVIO KOORDINACIJOS KAITUMAS

Ludovic Seifert[1], Leo Wattebled[1], Maxime L'Hermette[1], Romain Herault[2]
Ruano universitetas[1], Ruanas, Prancūzija
Taikomųjų mokslų nacionalinis institutas[2], Ruanas, Prancūzija

SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Alpinistai kopdami ledu patys pasidaro kilimo takus (skyles) batų kabliais ir ledkirčiais. Sušalusio krioklo aplinkoje tenka derinti rankų ir kojų darbą be iš anksto numatytų koordinacijos modelių.

Tikslas: išanalizuoti skirtingo meistriškumo ledo alpinistų rankų ir kojų koordinaciją stebint, kaip kopiantysis panaudoja aplinkos kliūtis (sušalusio krioklo ledo formas) judesiams atlikti.

Metodai. Šeši didelio meistriškumo ledo alpinistai ir penki pradedantieji kopė į 30 m aukščio sušalusį krioklį (atitinkamai 5 / 5+ ir 4 balų). Priekinė vaizdo kamera įrašinėjo rankų ir kojų darbą per pirmuosius 15 kilimo metrus. Buvo siekiama išanalizuoti rankų ir kojų bei jų tarpusavio koordinaciją.

Rezultatai. Fazinis rankų ir kojų koordinacijos režimas buvo pagrindinis atraktorius abiejose grupėse. Didelio meistriškumo ledo alpinistai, palyginti su pradedančiaisiais, parodė didesnį savo elgsenos kaitumą ieškodami įvairesnių rankų ir kojų judesių kampų (ypač vertikalių ir sukryžiuotų padėčių) ir judėjimo būdų (mojuodami ledkirčiais ir smeigdami kablius į ledą).

Aptarimas ir išvados. Galima teigti, kad skylės lede ir sušalusio krioklio ledo forma daro įtaką didelio meistriškumo ledo alpinistų rankų ir kojų koordinacijos kaitai, o pradedantieji alpinistai labiau naudojasi pastoviais judėjimo įgūdžiais pausiausvyrai išlaikyti.

Raktažodžiai: rankų ir kojų koordinacija, aplinkos kliūtys, judėjimo būdai.

Gauta 2010 m. rugsėjo 8 d.
Received on September 8, 2010

Priimta 2011 m. kovo 17 d.
Accepted on March 17, 2011

Corresponding author **Ludovic Seifert**
Université de Rouen
Faculté des Sciences du Sport
CETAPS
Boulevard Siegfried
76821 Mont-Saint-Aignan Cedex
France
Tel (33)-2 32 10 77 84
E-mail ludovic.seifert@univ-rouen.fr