Skill transfer specificity shapes perception and action under varying environmental constraints

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Generality and specificity of skill transfer shapes perception and action under varying environmental constraints

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Abstract

This study investigated the effect of generality and specificity of skill transfer processes in (re)organisation of perception and action. The task vehicle for this purpose was climbing (assessed by fluency or smoothness of the hip trajectory and climber orientation using normalized jerk coefficients) exhibited by participants adapting perception and action under varying environmental constraints in a climbing task. Twelve recreational climbers were divided in two groups: the first group completed a 10-m high route on an indoor climbing wall, while the second group completed a 10-m high route on an icefall in a top-rope condition. We maintained the same level of difficulty between these two performance environments. An inertial measurement unit was attached to the hips of each climber to collect 3D acceleration and 3D orientation data in order to compute jerk coefficient values. Results showed higher normalized jerk coefficient values for performance on the icefall route, perhaps due to greater functional complexity in perception and action when climbing ice falls, which requires use of specific tools for anchorage. Results emphasized that individuals solving different motor problems exhibited positive *general* transfer processes, but design of *specific* task constraints enabled participants to pick up specifying information for affordances of tool use in performing on an ice fall.

Key words: ecological dynamics, perception and action, embodied perception, affordance, tool use, transfer.

Introduction

Adapting perception and action couplings when regulating multi-articular movement patterns is a hallmark property of expertise, facilitating consistent performance achievements under different task and environmental constraints (Stone, North, Maynard, Panchuk & Davids, 2014; Panchuk, Davids, McMahon, Sakadjian & Parrington, 2013; Warren, 2006). Previous studies have provided insights on the adaptability of skilled performers, defined by their capacity to exploit functional variability in coordinating actions with dynamic performance environments. The data have illustrated how expert behaviours remain flexible, and are not stereotyped and rigid (Seifert, Button, et al., 2013; Warren, 2006). Traditional views on expertise acquisition, exemplified by the deliberate practice approach, have proposed that athletes need to accumulate 10,000 hours of intensely dedicated and specific practice (Ericsson, Krampe, & Tesch-Römer, 1993). This idea fails to account for how transfer processes may shorten the period of specialised practice needed for gaining expert status (for pertinent criticisms see Davids, 2000; Tucker & Collins, 2012). For example, in a study of chess masters, an astonishing range of 3,016–23,608 hours has been reported for the achievement of expertise (e.g., Grandmaster level) (Hambrick et al., 2014). These data on individual differences raise pertinent questions on how transfer processes can influence the timescales for expertise acquisition in different performance environments (Davids, 2015).

In an ecological dynamics theoretical framework, the capacity to transfer perceptions, cognitions and actions between performance environments is a critical feature of expertise that has been somewhat neglected in past research (Seifert et al., 2013). Skill transfer emerges from the influence of prior experiences under a specific set of interacting constraints on performance under a different set of conditions compared to those where the skills were originally acquired (Newell, 1996; Issurin, 2013; Rosalie & Muller, 2012). We have argued that *specificity* of transfer can emerge when the existing intrinsic dynamics (i.e. performance disposition or tendencies) of an individual *cooperate* with the dynamics of a new task to be learned, facilitating successful performance behaviours (e.g., Davids et al., 2015). In contrast, *general* transfer can occur when intrinsic and task dynamics do not cooperate closely. Specificity and generality of transfer can be influenced by the intrinsic dynamics of each individual learner, which are shaped by learning and previous experiences under specific task constraints (Davids et al., 2015).

These theoretical ideas have implications for implementing transfer processes that could constrain the degree and rate of performance improvement, as suggested by some important data from laboratory studies of coordination in finger movements (Zanone & Kelso, 1997). Despite these ideas, there have been few empirical studies of transfer processes during coordination of multi-articular actions in different performance environments (Rienhoff et al., 2013; Rosalie & Muller, 2012). Here, we sought to examine this relevant issue for expertise acquisition in performance environments requiring multi-articular actions by investigating whether the intrinsic dynamics of climbers who practise regularly on an indoor climbing wall might cooperate or compete with the task dynamics of climbing an ice fall. On an indoor climbing wall, routes consist of holds composed of similar smooth synthetic materials, which afford gripping with the fingers in an unchanging internal environment (e.g. ambient temperature remains the same during a climb). In ice climbing, properties of an icefall require use of tools on the feet (crampons) and in the hands (ice tools) and performance conditions can change markedly within and between climbs (Batoux & Seifert, 2007; Blanc-Gras & Ibarra, 2012). Ecological dynamics suggests that functional adaptation of existing perception-action couplings might be constrained by *specificity and generality* of transfer processes induced by such performance environments (Davids et al., 2015). *General* transfer is exemplified when processes of perception and action are generalised to a new set of performance constraints that, although different, maintain couplings among key system components. For example, this sub-system maintenance might include the coupling of visual and motor systems or the use of similar limb coordination patterns, but invoking different types of action patterns with the hand and feet when climbing (Seifert et al., 2014)). Other examples of *general* transfer between indoor and ice fall climbing might include the use of cognitions, perception and action to seek ascent routes, to manage weight with respect to the environmental constraint of gravity and the discovery of surface properties with exploratory actions. *Specific* transfer processes enhance the stability of certain perception-action couplings, which are refined through practice under highly particular task constraints to enhance performance, exemplified in ice fall climbing by the way that particular tools are used to ascend the surface. In indoor climbing such tools play no part in ascending a surface. An important research challenge is to effectively characterise different performance ecologies along each axis of transfer (specific and general), in order to predict how processes of skill transfer might support performance (through adaptation of an individual's intrinsic dynamics), shortening the timescales of learning. This is because the relationship between two performance environments is captured by numerous, dynamic and interacting constraints: environmental, task and personal (both structural e.g., strength, flexibility, height, and functional e.g., decision making, attunement and calibration to specifying information for action) (Davids, Button, & Bennett, 2008; Newell, 1986). Transferability of behaviours such as cognition, perception and action, between two performance domains hinges on the functionality of existing perception-action couplings and how much they may need to be specifically adapted for use in a different performance environment.

The issue of generality or specificity of transfer particularly relates to the capability of an individual to pick up information and utilise specific affordances under different performance conditions (Davids et al, 2015). The richness of the landscape of affordances raises important questions over the nature of learning designs that can help an individual to utilise relevant affordances in a given performance environment, i.e., through attunement and calibration to specifying information to regulate adaptive behaviours (Fajen, Riley, & Turvey, 2009).

The question we address here, using the task vehicle of climbing, concerns how affordances might be designed into practice landscapes which facilitate their utilisation, and the transfer of behaviours such as cognitions, perceptions and actions. It is possible that some practice task constraints might be too *general* for a particular individual, thereby lacking functionality and delaying the learning process. Indeed, the implemented learning design could, either exhibit a less rich landscape of available affordances, or could be too far from the intrinsic dynamics of an individual learner for them to be adapted to support performance (i.e. practice task designs might contain too much non-specifying information). Conversely, learning designs that specifically enhance transfer processes are likely to contain specifying information sources that favour the adaption of information-movement couplings, thus inviting further functional actions, accelerating the learning process (Withagen, de Poel, Araújo, & Pepping, 2012). The key point to note in this theoretical rationale is that learning designs which only support *general* transfer might lead to poorer quality (less efficient and effective) learning focused on using processes of perception, action and cognition at a general level, which might maintain skill levels at best. In contrast, inclusion of specifying information sources in designing learning environments is proposed to induce high quality learning leading to the establishment or enhancement of perception-movement couplings, which regulate functional performance behaviours. These ideas might explain the longer time periods needed by some individuals to acquire expertise, providing an ecological dynamics rationale for significant differences observed in time taken to attain expert status (Hambrick et al., 2014).

The multi-articular action of climbing offers rich landscapes of available affordances for studying effects of generality and specificity of skill transfer. This performance context is characterised by varying performance environments (variations in surfaces, e.g. smooth synthetics, rock or ice; surrounding conditions, e.g. variations in ambient temperatures, wind, available light, dryness/wetness; textures, e.g., smooth, rough, rocky, and slippery; and tool use, e.g., use of hands, feet, gloves, boots, ice tools, crampons, chalk). These environmental and task constraints interact to shape the emergence of perception-action couplings that have varying degrees of specificity with respect to the affordances available in different climbing environments. To exemplify, rock and ice climbing environments involve interspersed periods of behaviours dedicated to quadruped limb displacements on a vertical surface, alternated with periods in more or less static positions dedicated to exploring and grasping surface holds or ice tool anchorages (Fuss & Niegl, 2008; Pijpers, Oudejans, Bakker, & Beek, 2006; Seifert, Wattebled, et al., 2014; Sibella, Frosio, Schena, & Borghese, 2007), posture regulation (Bourdin, Teasdale, & Nougier, 1998; Bourdin, Teasdale, Nougier, Bard, & Fleury, 1999; Testa, Martin, & Debû, 1999, 2003), upper limb release and resting (Sanchez, Lambert, Jones, & Llewellyn, 2012), and "route finding" (Cordier, Mendès-France, Bolon, & Pailhous, 1993; Cordier, Mendès-France, Pailhous, & Bolon, 1994). In particular, three main properties might support general transfer of climbing experience between the task constraints of rock and ice climbing (Seifert, Wattebled, et al., 2013): (i) the unpredictability of performance environments requiring the continuous coupling of processes of perception and action, (ii) alternation between maintaining body equilibrium (stability) and climbing quickly up a vertical surface (transitioning), and (iii), the use of quadruped locomotion patterns subsequently involving the extremities of each limb to negotiate an ascent. The task constraints of ice climbing reveal at least three particularities in comparison to rock climbing which might induce *specificity* of transfer between each discipline (Seifert, Wattebled, et al., 2013): (i) Tools, such as ice tools for the hands and crampons for the feet, form parts of the landscape of available affordances used by an ice climber to interact with surfaces properties of an icefall, (ii) The icefall properties tend to be stochastically distributed throughout a particular frozen waterfall surface (for instance, the icefall texture can vary greatly, presenting more or fewer holes, thus inviting climbers to hook available holes or create their own holes by swinging their ice tools), and (iii), climbers can discover their own climbing path since they can create their own (more or less stable anchorages) with their tools and secure their ascent by inserting ice screws into specific locations on an icefall.

Previous results have revealed that experienced rock climbers, who had previously acquired multiple movement and coordination patterns, were able to transfer this large range of skills, and climbing fluency, to the novel task constraints of ice climbing (Seifert, Wattebled, et al., 2013). However, Seifert et al. (2013) did not examine whether the specificities of ice climbing (i.e. tool use; variability and temporary distribution of icefall properties; freely chosen climbing path) might induce *specific* transfer effects from climbing an indoor wall to an ice fall. For example, route finding is an important climbing skill that could provide information on the ability of climbers to utilise affordances from a surface to enhance their performance fluency. The influences of surface affordances could be revealed by analysing the ratio between different types of actions observed. In rock climbing, Pijpers et al. (2006) distinguished exploratory and performatory movements according to whether a potential hold on a climbing wall was touched, with or without it being used as support. Clearly, an excessive duration spent immobile during route finding and hold exploration may compromise climbing fluency, leading to enhanced physical and mental fatigue. Climbing fluency has been assessed previously by: (i) measuring the geometric index of entropy (Cordier et al., 1993, 1994; Sibella et al., 2007), (ii) the time spent in different states (movement/immobility) (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Seifert, Wattebled, et al., 2013; Seifert et al., 2014), and more recently (iii), by calculating the jerk coefficient (i.e., third time derivative of position or the rate of change of acceleration; Flash & Hogan, 1985; Hogan, 1984), previously used as an index of smoothness of 3D translations and 3D rotations of the hips (Seifert, Orth, et al., 2014).

The main aim of this study was to examine the constraints on *specific* transfer of cognitions, perception and action in indoor climbing relative to climbing on an ice fall. We sought to achieve this aim by assessing participants' route finding and climbing behaviours (i.e. by examining performance fluency evidenced through the jerk coefficient) within each context on a novel route. We anticipated that ice climbing would represent a rich performance landscape that allows the perception and utilisation of affordances to support vertical ascent. We expected that our analysis would reveal functions specific to the perception-action couplings required for satisfying constraints of performance on an ice fall. In particular, it was hypothesized that in ice climbing, only the *specific* transfer of fluent climbing behaviours would facilitate the emergence of a circular coupling between the individual, ice tool and icefall properties. We theorised that the *specificity* of transfer would be supported by the emergence of an *individual* - *ice tool* – *icefall* system. This *specificity* of transfer would be distinguished by data revealing the actualisation of ice *tool affordances*. It was also expected that the *generality* of transfer between previous experience on an indoor climbing wall and performance on an ice fall would be apparent, leading to some elementary benefits on performance revealed by the emergence of coupling of perception and action, management of body weight on the vertical surface and exploratory behaviours and exploratory activities.

Methods

Participants

Twelve recreational climbers who trained together at a local climbing facility, voluntarily participated in this study (mean age: 22.5 ± 2.7 yr; mean height: 171.3 ± 7.5 cm; mean weight: 69.6 ± 3.4 kg). These climbers had climbing experience of 3.8 ± 1.3 yr on an artificial climbing wall, trained for 3.7 ± 1.6 hours per week and had a rock climbing ability of 6a on the French Rating Scale of Difficulty (F-RSD) (Delignières, Famose, Thépeaut-Mathieu, & Fleurance, 1993), which corresponds to an intermediate level of performance (Draper et al., 2011). Climbing ability was defined as the most difficult ascent by top rope (Delignières et al., 1993). However, these climbers had no previous experience of ice climbing environments.

Protocol

The sample of twelve climbers was split in two groups of six climbers. The first group completed a 10-m high route on an artificial climbing wall in a top-roped condition, composed of 20 hand-holds, at a grade rated 5b on the F-RSD, which goes from 1 to 9. The second group completed 10-m high route on an icefall in a top-roped condition, in an air temperature of -8°C, at a grade rated 4 on the French rating scale, which goes from 1 to 7 (Batoux & Seifert, 2007). Grade 4 is a common grade assigned to recreational performers and involves an average slope of 75 to 80°, with steep or vertical sections (Batoux & Seifert, 2007). For this protocol, the icefall selected for the climbers was 10-m at around 80° slope. Each route was set by a professional mountain guide certified by the International Federation of Mountain Guides Association (IFMGA), who ensured that the grade of each route represented an equivalent level of climbing difficulty in terms of environmental performance constraints (according to Newell, 1986), and matched intermediate climbing levels. Participants were given general instructions to self-pace their ascent, climb fluently and climb without falling. Each ascent was preceded by 3 minutes of route preview, as a pre-ascent visual inspection is a key climbing performance parameter (Sanchez et al., 2012). The protocol was approved by the local University ethics committee and followed the declaration of Helsinki. Procedures were explained to the climbers, who then gave their written informed consent to participate.

Data collection

As with recent research on an indoor climbing wall (Seifert, Orth, et al., 2014), the originality in this study was the collect of tri-axial acceleration and tri-axial orientation data from an IMU located at the hip, in order to compute jerk as an indicator of climbing fluency. The IMU was integrated by combining a tri-axial accelerometer (±8G), tri-axial gyroscope ($1600°.s^{-1}$) and a tri-axial magnetometer (*MotionPod*, Movea©, Grenoble, France). Data collected from the IMU (with *MotionDevTool*, Movea©, Grenoble, France) were recorded with a North magnetic reference and at 100 Hz sampling frequency.

An operator also used a digital HD video camera to track the climber's movements through the indoor climbing route and on the ice climbing route.

Data analysis

Data analysis consisted of measuring: (i) climbing fluency by plotting the hip trajectory during performance and orientation using a jerk-based measure, and (ii), route finding behaviours from analysing the ratio between exploratory and performatory movements.

As stated previously, hip displacements of climbers not only correspond to 3D translations, but also to 3D orientations (Cordier, Dietrich, & Pailhous, 1996; Sibella et al., 2007; Zampagni, Brigadoi, Schena, Tosi, & Ivanenko, 2011). Therefore, in this study, climbing fluency was measured by computing hip trajectory and orientation smoothness via calculating the jerk coefficient. To determine either trajectory jerk or orientation jerk, the orientation of the sensor is required, first by removing the component due to gravity, since acceleration is measured in the sensor referential, and second, by determining the angular acceleration. By combining the accelerometer, gyroscope and magnetometer raw data, it was possible to compute orientation of the IMU with respect to the fixed frame of Earth reference (magnetic North, East and gravity directions) (Madgwick, Harrison, & Vaidyanathan, 2011). From this point, it is straightforward to calculate the acceleration of the hips in the fixed Earth reference frame, and then determine the jerk coefficient (for more details about the method and equations, see Seifert, Orth, et al., 2014). For a trajectory $x^{GF} \in C^3([O,T])$, the jerk $J_{x^{GF}}$was defined as:

$$J_{x^{GF}}(T) = C \int_0^T \left\| \dddot{x}_s^{GF} \right\|^2 ds \qquad \text{(equation 1)}$$

where C was a normalization constant to make the quantity dimensionless (Hogan & Sternad, 2009), depending on the height and the total climbing time T. In practice, instead of computing x_t^{GF} (position on the wall) from a_t^{GF} with successive integrations, the term $\dddot{x}_s^{GF}$ was replaced by $\dot{a}_t^{GF}$. By derivation of a_t^{GF}, the constant gravity acceleration was removed, leaving only the hip acceleration component. To compute the jerk coefficient $J_z(T)$, measuring the hip 3D orientation smoothness, a definition similar to Equation (1) was used, replacing the position acceleration by the angular acceleration (see Seifert, Orth, et al., 2014).

As stated previously, in rock climbing, Pijpers et al. (2006) distinguished exploratory and performatory touching movements of potential holds on a rock surface, with or without it being used as support during ascent. Assuming that affordances correspond to opportunities or invitations for action in a performance environment (Gibson, 1979; Rob Withagen et al., 2012), an analysis of the relations between exploratory and performatory movements could explain how climbers utilise affordances of rock surface features, i.e., to perceive 'climb-ability' of a surface and exploit environmental properties to act (Boschker, Bakker, & Michaels, 2002; Boschker & Bakker, 2002; Pijpers et al., 2006). Therefore, the capacity to utilise affordances in climbing performance could be approached by observing the ratio between touched holds and grasped holds, according to the ‘three-holds-rule’: skilled climbers negotiate a surface by touching fewer than three surface holds before grasping a functional one. Thus, data on exploratory and performatory movements were collected from video footage of performance, and the touched/grasped holds ratio was computed on the indoor climbing route.

A similar ratio has been adapted for performance analysis on an ice climbing route by plotting the ratio between repetitive swings of ice tools and the number of definitive anchorages (see Seifert, Wattebled, et al., 2013; Seifert, Wattebled, et al., 2014). The swinging/anchoring ratio of ice tool behaviours could reveal the attunement of each climber to icefall properties for exploitation, leading to greater levels of climbing fluency (i.e. low jerk values of hip trajectory and orientation). Indeed, when the ice is soft or ventilated, climbers can anchor their ice tools in one shot, whereas when the ice is dense and thick, climbers often need to repeat numerous swings of the ice tools to acquire a deep anchorage. Skilled climbers can typically detect variations in the thickness of an icefall (through perception of haptic information from the ice tool) in order to reduce the frequency of actions needed to acquire definitive anchorages (Blanc-Gras & Ibarra, 2012).

Statistical analysis

Normality of distribution and homogeneity of variance was checked before using parametric tests. Comparisons between indoor wall climbing and ice climbing conditions for jerk of hip trajectory $J_x(T)$, jerk of hip orientation $J_z(T)$, exploratory movements, performatory movements, total number of actions, the exploratory/performatory ratio, and time of ascent duration, were undertaken by Student *t*-tests with a level of statistical significance set at P<.05. Then, effect size for a Student *t*-test (i.e. Cohen's *d*; Cohen, 1988) was calculated, given the mean (m_X) and standard deviation (s_X) for two independent samples of equal size:

$$d = \frac{|m_1 - m_2|}{\sqrt{\left(s_1^2 - s_2^2\right)/2}}$$

For Cohen's d an effect size of 0.2 to 0.3 might be a "small" effect, around 0.5 a "medium" effect and 0.8 to infinity, a "large" effect (Cohen, 1988).

Results

Table 1 indicates a significantly higher jerk of hip trajectory $J_x(T)$ and jerk of hip orientation $J_z(T)$ in the ice climbing condition, supporting the view of lower levels of fluency when climbing frozen waterfalls, than on an indoor climbing wall. Moreover, climbers exhibited three times more actions and longer ascent duration to cover the same vertical distance in ice climbing than under the constraints of the indoor climbing wall (Table 1). These findings were explained by the fact that climbers realised significantly more exploratory movements in ice climbing than on the indoor climbing wall (Table 1); in particular, we observed one exploratory movement (i.e. one ice tool swing) for one ice tool anchorage during ice climbing, whereas there was one exploratory movement observed (i.e. one touched hold) during the whole ascent on the indoor climbing wall (i.e. 20 holds set by the setter). Therefore, a significantly higher exploratory/performatory movement ratio was observed in the ice climbing condition (Table 1).

Insert table 1 about here

Discussion

The results of this study confirmed the positive transfer of performance between climbing on an indoor climbing wall and ice climbing because all the participants were able to reach the top of the route without falling and resting. On the one hand, these results revealed the existence of *general* transfer processes between these two distinct task and environmental constraints supported by affordances for: (i) controlling their body weight on a vertical surface and counteracting the force of gravity, (ii) using different limb extremities to achieve a vertical displacement trajectory, and (iii), continuously coupling perception and action subsystems to negotiate the performance environments (e.g. exhibited by exploratory actions which led to successful ascents in the rock and ice climbing tasks). These findings on the effects of *general* transfer concur with data reported by Seifert et al. (2013) who showed that climbers with previous experience of an indoor climbing wall were able to transfer their stable perception-action couplings to an ice climbing task. Positive transfer at a *general* level was revealed when their participants exhibited higher levels of climbing fluency, fewer exploratory movements and a larger range of movement and coordination patterns than a group of novices (Wagman & Van Norman, 2011; Withagen & Michaels, 2002). For example, in the climbing task, transfer was observed to occur between performance on the indoor climbing wall and icefall environments when the ice tool was readily adapted to support the control of body weight and the use of extremities for ascent.

However, the more extensive exploration behaviours observed on the ice route, suggested the need for more *specific* perception-action couplings in the icefall environment to support the anchoring of the ice tool in existing *hook-able* structures, requiring further attunement to properties of surface holes in the participants. With practice in rock climbing, climbers seem able to calibrate hand-grasping patterns afforded by the shape of holds (Seifert, Orth, Hérault, & Davids, 2013). Similarly, ice climbers seem able to calibrate the ice tool actions (i.e. swinging *vs.* hooking) according to the density, thickness and temperature of the icefall. These examples emphasized that, in both the rock and ice climbing tasks, climbers were able to scale their perceptions and actions to environmental properties by exploiting exploratory behaviours, supporting the notion of *general* processes of transfer between the tasks. In other words, it seems that skill transfer from an indoor climbing wall to performance on an icefall only provides opportunities for *general* transfer because in the ice climbing task, skilled performance is predicated on the utilisation of specific affordances, i.e., a relationship that emerged from matching the perceived physical features of the ice tool (i.e. weight, location of centre of mass, camber of stick, blade resonance), of the icefall (e.g., density, temperature, thickness of the ice) and of the individual (i.e. performance goals, capacity for haptic perception, skill level, past experience).

These results confirmed that specificities of the ice climbing task (e.g. ice tool use) and icefall environment properties (e.g. shape, temperature, thickness and ice density) require the formation of specific perception-action couplings which can only emerge from climbing performance on an ice fall. We postulated that in an ice climbing task, the acquisition of a functional information-movement coupling would be facilitated through a circular coupling between the individual, ice tool and icefall properties, supporting the idea that the *individual - ice tool – icefall* system is supported by perception of ice *tool affordances*. This interpretation signifies that the climber needs to perceive the icefall properties through the use of the ice tools, and inversely, to use the ice tools, the climber must be able to pick up properties from the ice fall performance environment. Seifert et al. (2014) showed that, depending on the thickness and density of the icefall, the climbers could either hook existing holes with the blade of the ice tool or swing the ice tool when the icefall was very dense. Inversely, the blade of the ice tools could be used to perceive whether a hole was deep and "hook-able" or small and fragile, requiring participants to swing their ice tools. Gibson (1979) foreshadowed these observations in arguing that "*when in use, a tool is a sort of extension of the hand, almost an attachment to it or a part of the user's own body, and thus is no longer a part of the environment of the user. But when not in use, the tool is simply a detached object of the environment, graspable and portable, to be sure, but nevertheless external to the observer*" (p. 41). Previous experiments have already explored the ability of individual to detect tool affordance by dynamic touch, showing that the tool mass distribution in terms of the inertia tensor provided basis to distinguish tool properties for actions (Wagman & Carello, 2001, 2003). Our study provided data on how each individual interacted with ice tool properties, according to the icefall properties, and the task goal of anchoring the blade of the ice tool. Skill-based differences have already been reported in previous work revealing how beginners tended to swing the ice tool into the icefall to create their own anchorage because they were unable to perceive affordances for anchorage from existing holes in the ice fall (Seifert, Wattebled, et al., 2014). Conversely, expert climbers showed much more adaptive flexibility in using their ice tools in many different manners: as a broom to clean the stalactites that mask a dense zone of ice, as a hammer that they can swing into the icefall to create deep holes when needed, and as a hook to use exploit holes or steps (Seifert et al., 2014). Skilled individuals tended to adopt tool use behaviours that minimized biomechanical costs of performance (Jacquet et al., 2012). Our results showed both greater frequency of exploratory (i.e. ice tool swinging) and performatory movements (i.e. ice tool anchoring) on the icefall rather than on an indoor wall climbing. These results indicated higher biomechanical costs (exemplified by higher jerk coefficient of hip trajectory and orientation), lower tool affordance detection and icefall affordances detection in ice climbing. In other words, climbers practising on an indoor climbing wall are not able to *fully* exploit the specific richness of the landscape of affordances offered when performing on an ice fall (i.e. including both environmental and ice tool functional features that contribute to the landscape of available affordances; Bruineberg & Rietveld, 2014). Therefore, climbers need to be able to gain specific experience by exploring both environmental constraints and functional features of tools to achieve their task goals in different climbing environments. Through analysis of skill transfer processes from an indoor wall climbing to an ice climbing environment, our study emphasized the ability of climbers to exhibit positive *general* transfer (i.e. ability to reach the top of the route without falls and rests), but with lower levels of climbing fluency due to the specificity of ice tool and icefall affordances. In particular, ice tool anchorage is often viewed as a challenging action by beginners for whom a confident anchorage means a deep anchorage where the blade does not move (Seifert et al., 2014). A deep and stable blade anchorage is often achieved through repetitive ice tool swinging. The action of anchorage and de-anchorage is specific to ice tool use and might explain the higher values of jerk coefficients in ice climbing. In conclusion, our results demonstrated that an ice climbing task provided specifying information for the performance of specific functional behaviours. Notably, ice climbers need to be attuned and calibrated to key functional and dynamical features of an icefall and ice tools. This study suggested that tasks, which involve specific transfer processes would enable learner to perceive relevant functional affordances by specifying adaptive movement patterns to satisfy interacting performance constraints.

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Table caption

Table 1. Comparison between indoor wall climbing and ice climbing conditions for jerk of hip trajectory $J_x(T)$, jerk of hip orientation $J_z(T)$, exploratory movements, performatory movements, total number of actions, exploratory/performatory ratio and ascent duration.

Task	Participant	Jerk for hip trajectory	Jerk for hip orientation	Touched holds	Grasped holds	Total number of hand actions	Ratio touched/grasped	Ascent duration (s)
indoor wall climbing	1	1.78E+11	1.82E+08	1	23	24	0.04	146
	2	2.03E+11	3.02E+08	1	25	26	0.04	81
	3	3.07E+11	4.28E+08	1	23	24	0.04	72
	4	2.99E+11	1.54E+08	3	23	26	0.13	133
	5	3.30E+11	1.83E+08	1	25	26	0.04	141
	6	6.71E+10	7.51E+07	1	20	21	0.05	71
	Mean	2.31E+11	2.21E+08	1.3	23.2	24.5	0.06	107.3
	SD	*1.01E+11*	*1.25E+08*	*0.8*	*1.8*	*2.0*	*0.04*	*36.2*
				ice tool swinging	ice tool anchorage	Total number of ice tool actions	Ratio swinging/anchorage	Ascent duration (s)
ice climbing	1	2.09E+16	3.74E+11	16	30	46	0.53	270
	2	3.17E+16	5.36E+11	54	40	94	1.35	410
	3	3.66E+16	1.08E+12	21	32	53	0.66	230
	4	8.85E+14	5.50E+10	29	46	75	0.63	320
	5	1.02E+17	2.04E+12	35	36	71	0.97	420
	6	9.84E+15	3.23E+11	24	36	60	0.67	282
	Mean	3.36E+16	7.35E+11	29.8	36.7	66.5	0.80	322.0
	SD	*3.60E+16*	*7.24E+11*	*13.5*	*5.8*	*17.3*	*0.31*	*77.6*
Statistics	*t*-test	$t_{10} = -2.29$	$t_{10} = -2.48$	$t_{10} = -5.15$	$t_{10} = -5.48$	$t_{10} = -5.91$	$t_{10} = -5.91$	$t_{10} = -6.14$
	Cohen's *d*	1.32	1.44	2.97	3.16	3.41	3.41	3.54

t-value was only presented when the Student *t*-test was significant with a level of significance at $P<.05$.

Figure captions

Figure 1. 10-m height indoor climbing route with 20 numbered holds (left panel) and 10-m height icefall route with two horizontal lines delimiting the 10-m section (right panel).

Figure 2. Example of tri-dimensional acceleration (in Earth reference) used for jerk computation of hips trajectory (top left panel for one ice climber, lower left panel for one climber in indoor climbing wall) and of tri-dimensional orientation used for jerk computation of hips orientation (top right panel for one ice climber, lower right panel for one climber in indoor climbing wall) showing higher activity and leading to higher jerk coefficient for ice climber.

Figure 1

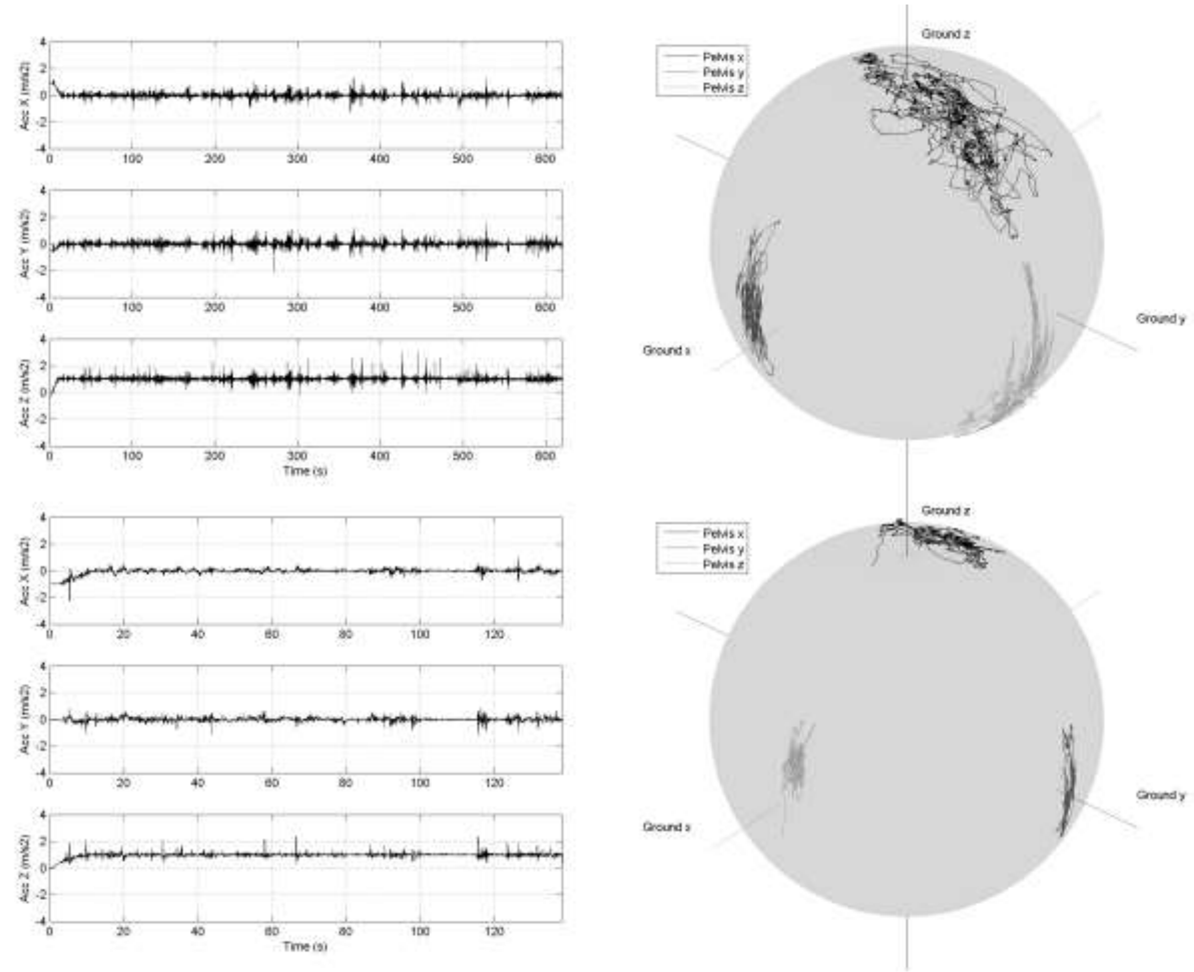
Acc X (m/s2)
Acc Y (m/s2)
Acc Z (m/s2)
Time (s)
Pelvis x
Pelvis y
Pelvis z
Ground z
Ground y
Ground x

Figure 2